

	Section	Page
1. Introduction	1	3
2. The character set	17	11
3. Input and output	25	14
4. String handling	38	20
5. On-line and off-line printing	54	25
6. Reporting errors	72	31
7. Arithmetic with scaled dimensions	99	39
7b. Random numbers	110	43
8. Packed data	128	50
9. Dynamic memory allocation	133	52
10. Data structures for boxes and their friends	151	58
11. Memory layout	180	67
12. Displaying boxes	191	71
13. Destroying boxes	217	79
14. Copying boxes	221	81
15. The command codes	225	83
16. The semantic nest	229	87
17. The table of equivalents	238	92
18. The hash table	274	118
19. Saving and restoring equivalents	290	127
20. Token lists	311	134
21. Introduction to the syntactic routines	319	138
22. Input stacks and states	322	141
23. Maintaining the input stacks	343	151
24. Getting the next token	354	154
25. Expanding the next token	388	165
26. Basic scanning subroutines	428	177
27. Building token lists	490	200
28. Conditional processing	513	215
29. File names	537	223
30. Font metric data	565	232
31. Device-independent file format	610	251
32. Shipping pages out	619	257
32a. pdfTEX basic	672	277
32b. pdfTEX output low-level subroutines	679	281
32c. PDF page description	691	291
32d. The cross-reference table	694	298
32e. Font processing	703	311
32f. PDF shipping out	727	330
33. Packaging	814	362
34. Data structures for math mode	854	378
35. Subroutines for math mode	873	387
36. Typesetting math formulas	893	394
37. Alignment	942	414
38. Breaking paragraphs into lines	987	431
39. Breaking paragraphs into lines, continued	1036	454
40. Pre-hyphenation	1066	468
41. Post-hyphenation	1075	472
42. Hyphenation	1094	482
43. Initializing the hyphenation tables	1117	488
44. Breaking vertical lists into pages	1142	498
45. The page builder	1155	504

46. The chief executive	1204	521
47. Building boxes and lists	1231	533
48. Building math lists	1312	556
49. Mode-independent processing	1384	575
50. Dumping and undumping the tables	1475	598
51. The main program	1508	609
52. Debugging	1516	615
53. Extensions	1518	617
53a. The extended features of ε -T _E X	1645	671
54. System-dependent changes	1864	736
55. Index	1865	737

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1. Introduction. This is ε -T_EX, a program derived from and extending the capabilities of T_EX, a document compiler intended to produce typesetting of high quality. The Pascal program that follows is the definition of T_EX82, a standard version of T_EX that is designed to be highly portable so that identical output will be obtainable on a great variety of computers.

The main purpose of the following program is to explain the algorithms of T_EX as clearly as possible. As a result, the program will not necessarily be very efficient when a particular Pascal compiler has translated it into a particular machine language. However, the program has been written so that it can be tuned to run efficiently in a wide variety of operating environments by making comparatively few changes. Such flexibility is possible because the documentation that follows is written in the WEB language, which is at a higher level than Pascal; the preprocessing step that converts WEB to Pascal is able to introduce most of the necessary refinements. Semi-automatic translation to other languages is also feasible, because the program below does not make extensive use of features that are peculiar to Pascal.

A large piece of software like T_EX has inherent complexity that cannot be reduced below a certain level of difficulty, although each individual part is fairly simple by itself. The WEB language is intended to make the algorithms as readable as possible, by reflecting the way the individual program pieces fit together and by providing the cross-references that connect different parts. Detailed comments about what is going on, and about why things were done in certain ways, have been liberally sprinkled throughout the program. These comments explain features of the implementation, but they rarely attempt to explain the T_EX language itself, since the reader is supposed to be familiar with *The T_EXbook*.

2. The present implementation has a long ancestry, beginning in the summer of 1977, when Michael F. Plass and Frank M. Liang designed and coded a prototype based on some specifications that the author had made in May of that year. This original protoTeX included macro definitions and elementary manipulations on boxes and glue, but it did not have line-breaking, page-breaking, mathematical formulas, alignment routines, error recovery, or the present semantic nest; furthermore, it used character lists instead of token lists, so that a control sequence like `\halign` was represented by a list of seven characters. A complete version of TeX was designed and coded by the author in late 1977 and early 1978; that program, like its prototype, was written in the SAIL language, for which an excellent debugging system was available. Preliminary plans to convert the SAIL code into a form somewhat like the present “web” were developed by Luis Trabb Pardo and the author at the beginning of 1979, and a complete implementation was created by Ignacio A. Zabala in 1979 and 1980. The TeX82 program, which was written by the author during the latter part of 1981 and the early part of 1982, also incorporates ideas from the 1979 implementation of TeX in MESA that was written by Leonidas Guibas, Robert Sedgewick, and Douglas Wyatt at the Xerox Palo Alto Research Center. Several hundred refinements were introduced into TeX82 based on the experiences gained with the original implementations, so that essentially every part of the system has been substantially improved. After the appearance of “Version 0” in September 1982, this program benefited greatly from the comments of many other people, notably David R. Fuchs and Howard W. Trickey. A final revision in September 1989 extended the input character set to eight-bit codes and introduced the ability to hyphenate words from different languages, based on some ideas of Michael J. Ferguson.

No doubt there still is plenty of room for improvement, but the author is firmly committed to keeping TeX82 “frozen” from now on; stability and reliability are to be its main virtues.

On the other hand, the WEB description can be extended without changing the core of TeX82 itself, and the program has been designed so that such extensions are not extremely difficult to make. The *banner* string defined here should be changed whenever TeX undergoes any modifications, so that it will be clear which version of TeX might be the guilty party when a problem arises.

This program contains code for various features extending TeX, therefore this program is called ‘ ε -TeX’ and not ‘TeX’; the official name ‘TeX’ by itself is reserved for software systems that are fully compatible with each other. A special test suite called the “TRIP test” is available for helping to determine whether a particular implementation deserves to be known as ‘TeX’ [cf. Stanford Computer Science report CS1027, November 1984].

A similar test suite called the “e-TRIP test” is available for helping to determine whether a particular implementation deserves to be known as ‘ ε -TeX’.

```

define eTeX_version = 2 { \eTeXversion }
define eTeX_revision ≡ ".6" { \eTeXrevision }
define eTeX_version_string ≡ ‘-2.6’ { current  $\varepsilon$ -TeX version }
define eTeX_banner ≡ ‘This is  $\varepsilon$ -TeX, Version 3.141592653’, eTeX_version_string
    { printed when  $\varepsilon$ -TeX starts }

define pdfTeX_version ≡ 140 { \pdfTeXversion }
define pdfTeX_revision ≡ "22" { \pdfTeXrevision }
define pdfTeX_version_string ≡ ‘-1.40.22’ { current pdfTeX version }
define pdfTeX_banner ≡ ‘This is pdfTeX, Version 3.141592653’, eTeX_version_string,
    pdfTeX_version_string { printed when pdfTeX starts }

define TeX_banner ≡ ‘This is TeX, Version 3.141592653’ { printed when TeX starts }
define banner ≡ pdfTeX_banner
define TEX ≡ PDFTEX { change program name into PDFTEX }
define TeXXeT_code = 0 { the TeX--XqT feature is optional }
define eTeX_states = 1 { number of  $\varepsilon$ -TeX state variables in eqtb }

```

3. Different Pascals have slightly different conventions, and the present program expresses \TeX in terms of the Pascal that was available to the author in 1982. Constructions that apply to this particular compiler, which we shall call Pascal-H, should help the reader see how to make an appropriate interface for other systems if necessary. (Pascal-H is Charles Hedrick’s modification of a compiler for the DECsystem-10 that was originally developed at the University of Hamburg; cf. *Software—Practice and Experience* **6** (1976), 29–42. The \TeX program below is intended to be adaptable, without extensive changes, to most other versions of Pascal, so it does not fully use the admirable features of Pascal-H. Indeed, a conscious effort has been made here to avoid using several idiosyncratic features of standard Pascal itself, so that most of the code can be translated mechanically into other high-level languages. For example, the ‘**with**’ and ‘*new*’ features are not used, nor are pointer types, set types, or enumerated scalar types; there are no ‘**var**’ parameters, except in the case of files — $\varepsilon\text{-}\text{\TeX}$, however, does use ‘**var**’ parameters for the *reverse* function; there are no tag fields on variant records; there are no assignments *real* \leftarrow *integer*; no procedures are declared local to other procedures.)

The portions of this program that involve system-dependent code, where changes might be necessary because of differences between Pascal compilers and/or differences between operating systems, can be identified by looking at the sections whose numbers are listed under ‘system dependencies’ in the index. Furthermore, the index entries for ‘dirty Pascal’ list all places where the restrictions of Pascal have not been followed perfectly, for one reason or another.

Incidentally, Pascal’s standard *round* function can be problematical, because it disagrees with the IEEE floating-point standard. Many implementors have therefore chosen to substitute their own home-grown rounding procedure.

4. The program begins with a normal Pascal program heading, whose components will be filled in later, using the conventions of **WEB**. For example, the portion of the program called ‘⟨Global variables 13⟩’ below will be replaced by a sequence of variable declarations that starts in §13 of this documentation. In this way, we are able to define each individual global variable when we are prepared to understand what it means; we do not have to define all of the globals at once. Cross references in §13, where it says “See also sections 20, 26, . . .,” also make it possible to look at the set of all global variables, if desired. Similar remarks apply to the other portions of the program heading.

Actually the heading shown here is not quite normal: The **program** line does not mention any *output* file, because Pascal-H would ask the \TeX user to specify a file name if *output* were specified here.

```

define mtype  $\equiv$  t@&y@&p@&e { this is a WEB coding trick: }
format mtype  $\equiv$  type { ‘mtype’ will be equivalent to ‘type’ }
format type  $\equiv$  true { but ‘type’ will not be treated as a reserved word }

⟨Compiler directives 9⟩
program TEX; { all file names are defined dynamically }
label ⟨Labels in the outer block 6⟩
const ⟨Constants in the outer block 11⟩
mtype ⟨Types in the outer block 18⟩
var ⟨Global variables 13⟩

procedure initialize; { this procedure gets things started properly }
  var ⟨Local variables for initialization 19⟩
  begin ⟨Initialize whatever  $\text{\TeX}$  might access 8⟩
  end;

⟨Basic printing procedures 57⟩
⟨Error handling procedures 78⟩

```

5. The overall \TeX program begins with the heading just shown, after which comes a bunch of procedure declarations and function declarations. Finally we will get to the main program, which begins with the comment ‘*start.here*’. If you want to skip down to the main program now, you can look up ‘*start.here*’ in the index. But the author suggests that the best way to understand this program is to follow pretty much the order of \TeX ’s components as they appear in the [WEB](#) description you are now reading, since the present ordering is intended to combine the advantages of the “bottom up” and “top down” approaches to the problem of understanding a somewhat complicated system.

6. Three labels must be declared in the main program, so we give them symbolic names.

```
define start_of_TEX = 1 { go here when  $\text{\TeX}$ ’s variables are initialized }
define end_of_TEX = 9998 { go here to close files and terminate gracefully }
define final_end = 9999 { this label marks the ending of the program }
```

⟨Labels in the outer block 6⟩ ≡

```
start_of_TEX, end_of_TEX, final_end; { key control points }
```

This code is used in [section 4](#).

7. Some of the code below is intended to be used only when diagnosing the strange behavior that sometimes occurs when \TeX is being installed or when system wizards are fooling around with \TeX without quite knowing what they are doing. Such code will not normally be compiled; it is delimited by the codewords ‘**debug ... gubed**’, with apologies to people who wish to preserve the purity of English.

Similarly, there is some conditional code delimited by ‘**stat ... tats**’ that is intended for use when statistics are to be kept about \TeX ’s memory usage. The **stat ... tats** code also implements diagnostic information for `\tracingparagraphs`, `\tracingpages`, and `\tracingrestores`.

```
define debug ≡ @ { change this to ‘debug ≡ ’ when debugging }
define gubed ≡ @ { change this to ‘gubed ≡ ’ when debugging }
format debug ≡ begin
format gubed ≡ end

define stat ≡ @ { change this to ‘stat ≡ ’ when gathering usage statistics }
define tats ≡ @ { change this to ‘tats ≡ ’ when gathering usage statistics }
format stat ≡ begin
format tats ≡ end
```

8. This program has two important variations: (1) There is a long and slow version called `INITEX`, which does the extra calculations needed to initialize \TeX ’s internal tables; and (2) there is a shorter and faster production version, which cuts the initialization to a bare minimum. Parts of the program that are needed in (1) but not in (2) are delimited by the codewords ‘**init ... tini**’.

```
define init ≡ { change this to ‘init ≡ @ {’ in the production version }
define tini ≡ { change this to ‘tini ≡ @ {’ in the production version }
format init ≡ begin
format tini ≡ end
```

⟨Initialize whatever \TeX might access 8⟩ ≡

⟨Set initial values of key variables 21⟩

```
init ⟨Initialize table entries (done by INITEX only) 182⟩ tini
```

This code is used in [section 4](#).

9. If the first character of a Pascal comment is a dollar sign, Pascal-H treats the comment as a list of “compiler directives” that will affect the translation of this program into machine language. The directives shown below specify full checking and inclusion of the Pascal debugger when T_EX is being debugged, but they cause range checking and other redundant code to be eliminated when the production system is being generated. Arithmetic overflow will be detected in all cases.

⟨Compiler directives 9⟩ ≡
 @{@&\$C−, A+, D−@} { no range check, catch arithmetic overflow, no debug overhead }
debug @{@&\$C+, D+@} **gubed** { but turn everything on when debugging }

This code is used in section 4.

10. This T_EX implementation conforms to the rules of the *Pascal User Manual* published by Jensen and Wirth in 1975, except where system-dependent code is necessary to make a useful system program, and except in another respect where such conformity would unnecessarily obscure the meaning and clutter up the code: We assume that **case** statements may include a default case that applies if no matching label is found. Thus, we shall use constructions like

```

case x of
1: ⟨code for x = 1⟩;
3: ⟨code for x = 3⟩;
othercases ⟨code for x ≠ 1 and x ≠ 3⟩
endcases

```

since most Pascal compilers have plugged this hole in the language by incorporating some sort of default mechanism. For example, the Pascal-H compiler allows ‘*others:*’ as a default label, and other Pascals allow syntaxes like ‘**else**’ or ‘**otherwise**’ or ‘*otherwise:*’, etc. The definitions of **othercases** and **endcases** should be changed to agree with local conventions. Note that no semicolon appears before **endcases** in this program, so the definition of **endcases** should include a semicolon if the compiler wants one. (Of course, if no default mechanism is available, the **case** statements of T_EX will have to be laboriously extended by listing all remaining cases. People who are stuck with such Pascals have, in fact, done this, successfully but not happily!)

```

define othercases ≡ others: { default for cases not listed explicitly }
define endcases ≡ end { follows the default case in an extended case statement }
format othercases ≡ else
format endcases ≡ end

```

11. The following parameters can be changed at compile time to extend or reduce T_EX's capacity. They may have different values in INITEX and in production versions of T_EX.

⟨ Constants in the outer block 11 ⟩ ≡

```

mem_max = 30000;
    { greatest index in TEX's internal mem array; must be strictly less than max_halfword; must be
    equal to mem_top in INITEX, otherwise  $\geq$  mem_top }
mem_min = 0; { smallest index in TEX's internal mem array; must be min_halfword or more; must be
    equal to mem_bot in INITEX, otherwise  $\leq$  mem_bot }
buf_size = 500; { maximum number of characters simultaneously present in current lines of open files
    and in control sequences between \csname and \endcsname; must not exceed max_halfword }
error_line = 72; { width of context lines on terminal error messages }
half_error_line = 42; { width of first lines of contexts in terminal error messages; should be between 30
    and error_line - 15 }
max_print_line = 79; { width of longest text lines output; should be at least 60 }
stack_size = 200; { maximum number of simultaneous input sources }
max_in_open = 6;
    { maximum number of input files and error insertions that can be going on simultaneously }
font_max = 75; { maximum internal font number; must not exceed max_quarterword and must be at
    most font_base + 256 }
font_mem_size = 20000; { number of words of font_info for all fonts }
param_size = 60; { maximum number of simultaneous macro parameters }
nest_size = 40; { maximum number of semantic levels simultaneously active }
max_strings = 3000; { maximum number of strings; must not exceed max_halfword }
string_vacancies = 8000; { the minimum number of characters that should be available for the user's
    control sequences and font names, after TEX's own error messages are stored }
pool_size = 32000; { maximum number of characters in strings, including all error messages and help
    texts, and the names of all fonts and control sequences; must exceed string_vacancies by the total
    length of TEX's own strings, which is currently about 23000 }
save_size = 600; { space for saving values outside of current group; must be at most max_halfword }
trie_size = 8000; { space for hyphenation patterns; should be larger for INITEX than it is in production
    versions of TEX }
trie_op_size = 500; { space for "opcodes" in the hyphenation patterns }
dvi_buf_size = 800; { size of the output buffer; must be a multiple of 8 }
file_name_size = 40; { file names shouldn't be longer than this }
pool_name = `TeXformats:TEX.POOLXXXXXXXXXXXXXXXXXXXXXXXXXXXX';
    { string of length file_name_size; tells where the string pool appears }

```

See also sections 675, 679, 695, 721, and 1628.

This code is used in section 4.

12. Like the preceding parameters, the following quantities can be changed at compile time to extend or reduce TeX’s capacity. But if they are changed, it is necessary to rerun the initialization program INITEX to generate new tables for the production TeX program. One can’t simply make helter-skelter changes to the following constants, since certain rather complex initialization numbers are computed from them. They are defined here using WEB macros, instead of being put into Pascal’s **const** list, in order to emphasize this distinction.

```
define mem_bot = 0
    { smallest index in the mem array dumped by INITEX; must not be less than mem_min }
define mem_top ≡ 30000 { largest index in the mem array dumped by INITEX; must be substantially
    larger than mem_bot and not greater than mem_max }
define font_base = 0 { smallest internal font number; must not be less than min_quarterword }
define hash_size = 2100 { maximum number of control sequences; it should be at most about
    (mem_max − mem_min)/10 }
define hash_prime = 1777 { a prime number equal to about 85% of hash_size }
define hyph_size = 307 { another prime; the number of \hyphenation exceptions }
```

13. In case somebody has inadvertently made bad settings of the “constants,” TeX checks them using a global variable called *bad*.

This is the first of many sections of TeX where global variables are defined.

⟨Global variables 13⟩ ≡

bad: integer; { is some “constant” wrong? }

See also sections 20, 26, 30, 32, 39, 50, 54, 73, 76, 79, 96, 104, 110, 117, 133, 134, 135, 136, 142, 183, 191, 199, 231, 264, 271, 274, 275, 293, 308, 319, 323, 326, 327, 330, 331, 332, 355, 383, 389, 408, 413, 414, 436, 464, 473, 506, 515, 519, 538, 539, 546, 553, 558, 565, 575, 576, 581, 619, 622, 632, 643, 676, 680, 687, 691, 696, 701, 704, 708, 710, 723, 774, 809, 816, 817, 819, 827, 835, 858, 893, 898, 938, 944, 988, 995, 997, 999, 1002, 1007, 1013, 1021, 1046, 1067, 1075, 1080, 1082, 1096, 1101, 1118, 1122, 1125, 1146, 1155, 1157, 1164, 1207, 1250, 1442, 1457, 1475, 1481, 1509, 1520, 1523, 1541, 1545, 1548, 1555, 1557, 1568, 1581, 1625, 1630, 1637, 1649, 1657, 1702, 1747, 1770, 1811, 1813, 1832, 1839, 1855, and 1856.

This code is used in section 4.

14. Later on we will say ‘if *mem_max* ≥ *max_halfword* then *bad* ← 14’, or something similar. (We can’t do that until *max_halfword* has been defined.)

⟨Check the “constant” values for consistency 14⟩ ≡

```
bad ← 0;
if (half_error_line < 30) ∨ (half_error_line > error_line − 15) then bad ← 1;
if max_print_line < 60 then bad ← 2;
if dvi_buf_size mod 8 ≠ 0 then bad ← 3;
if mem_bot + 1100 > mem_top then bad ← 4;
if hash_prime > hash_size then bad ← 5;
if max_in_open ≥ 128 then bad ← 6;
if mem_top < 256 + 11 then bad ← 7; { we will want null_list > 255 }
```

See also sections 129, 312, 548, and 1425.

This code is used in section 1510.

15. Labels are given symbolic names by the following definitions, so that occasional **goto** statements will be meaningful. We insert the label *exit* just before the **end** of a procedure in which we have used the **return** statement defined below; the label *restart* is occasionally used at the very beginning of a procedure; and the label *reswitch* is occasionally used just prior to a **case** statement in which some cases change the conditions and we wish to branch to the newly applicable case. Loops that are set up with the **loop** construction defined below are commonly exited by going to *done* or to *found* or to *not_found*, and they are sometimes repeated by going to *continue*. If two or more parts of a subroutine start differently but end up the same, the shared code may be gathered together at *common_ending*.

Incidentally, this program never declares a label that isn't actually used, because some fussy Pascal compilers will complain about redundant labels.

```

define exit = 10   { go here to leave a procedure }
define restart = 20 { go here to start a procedure again }
define reswitch = 21 { go here to start a case statement again }
define continue = 22 { go here to resume a loop }
define done = 30   { go here to exit a loop }
define done1 = 31  { like done, when there is more than one loop }
define done2 = 32  { for exiting the second loop in a long block }
define done3 = 33  { for exiting the third loop in a very long block }
define done4 = 34  { for exiting the fourth loop in an extremely long block }
define done5 = 35  { for exiting the fifth loop in an immense block }
define done6 = 36  { for exiting the sixth loop in a block }
define found = 40   { go here when you've found it }
define found1 = 41  { like found, when there's more than one per routine }
define found2 = 42  { like found, when there's more than two per routine }
define not_found = 45 { go here when you've found nothing }
define not_found1 = 46 { like not_found, when there's more than one }
define not_found2 = 47 { like not_found, when there's more than two }
define not_found3 = 48 { like not_found, when there's more than three }
define not_found4 = 49 { like not_found, when there's more than four }
define common_ending = 50 { go here when you want to merge with another branch }

```

16. Here are some macros for common programming idioms.

```

define incr(#) ≡ # ← # + 1 { increase a variable by unity }
define decr(#) ≡ # ← # - 1 { decrease a variable by unity }
define negate(#) ≡ # ← -# { change the sign of a variable }
define loop ≡ while true do { repeat over and over until a goto happens }
format loop ≡ xclause { WEB's xclause acts like 'while true do' }
define do_nothing ≡ { empty statement }
define return ≡ goto exit { terminate a procedure call }
format return ≡ nil
define empty = 0 { symbolic name for a null constant }

```

17. The character set. In order to make TeX readily portable to a wide variety of computers, all of its input text is converted to an internal eight-bit code that includes standard ASCII, the “American Standard Code for Information Interchange.” This conversion is done immediately when each character is read in. Conversely, characters are converted from ASCII to the user’s external representation just before they are output to a text file.

Such an internal code is relevant to users of TeX primarily because it governs the positions of characters in the fonts. For example, the character ‘A’ has ASCII code 65 = ‘101’, and when TeX typesets this letter it specifies character number 65 in the current font. If that font actually has ‘A’ in a different position, TeX doesn’t know what the real position is; the program that does the actual printing from TeX’s device-independent files is responsible for converting from ASCII to a particular font encoding.

TeX’s internal code also defines the value of constants that begin with a reverse apostrophe; and it provides an index to the `\catcode`, `\mathcode`, `\uccode`, `\lccode`, and `\delcode` tables.

18. Characters of text that have been converted to TeX’s internal form are said to be of type *ASCII_code*, which is a subrange of the integers.

⟨Types in the outer block 18⟩ ≡
ASCII_code = 0 .. 255; { eight-bit numbers }

See also sections 25, 38, 101, 109, 131, 168, 230, 291, 322, 574, 621, 694, 707, 722, 1095, 1100, 1624, 1629, and 1675.

This code is used in section 4.

19. The original Pascal compiler was designed in the late 60s, when six-bit character sets were common, so it did not make provision for lowercase letters. Nowadays, of course, we need to deal with both capital and small letters in a convenient way, especially in a program for typesetting; so the present specification of TeX has been written under the assumption that the Pascal compiler and run-time system permit the use of text files with more than 64 distinguishable characters. More precisely, we assume that the character set contains at least the letters and symbols associated with ASCII codes ‘40 through ‘176; all of these characters are now available on most computer terminals.

Since we are dealing with more characters than were present in the first Pascal compilers, we have to decide what to call the associated data type. Some Pascals use the original name *char* for the characters in text files, even though there now are more than 64 such characters, while other Pascals consider *char* to be a 64-element subrange of a larger data type that has some other name.

In order to accommodate this difference, we shall use the name *text_char* to stand for the data type of the characters that are converted to and from *ASCII_code* when they are input and output. We shall also assume that *text_char* consists of the elements *chr(first_text_char)* through *chr(last_text_char)*, inclusive. The following definitions should be adjusted if necessary.

define *text_char* ≡ *char* { the data type of characters in text files }
define *first_text_char* = 0 { ordinal number of the smallest element of *text_char* }
define *last_text_char* = 255 { ordinal number of the largest element of *text_char* }

⟨Local variables for initialization 19⟩ ≡
i: integer;

See also sections 181 and 1102.

This code is used in section 4.

20. The TeX processor converts between ASCII code and the user’s external character set by means of arrays *xord* and *xchr* that are analogous to Pascal’s *ord* and *chr* functions.

⟨Global variables 13⟩ +≡
xord: **array** [*text_char*] **of** *ASCII_code*; { specifies conversion of input characters }
xchr: **array** [*ASCII_code*] **of** *text_char*; { specifies conversion of output characters }

21. Since we are assuming that our Pascal system is able to read and write the visible characters of standard ASCII (although not necessarily using the ASCII codes to represent them), the following assignment statements initialize the standard part of the *xchr* array properly, without needing any system-dependent changes. On the other hand, it is possible to implement TeX with less complete character sets, and in such cases it will be necessary to change something here.

```
(Set initial values of key variables 21) ≡
  xchr[40] ← '□'; xchr[41] ← '!'; xchr[42] ← '"'; xchr[43] ← '#'; xchr[44] ← '$';
  xchr[45] ← '%'; xchr[46] ← '&'; xchr[47] ← ''';
  xchr[50] ← '('; xchr[51] ← ')'; xchr[52] ← '*'; xchr[53] ← '+'; xchr[54] ← ',';
  xchr[55] ← '-'; xchr[56] ← '.'; xchr[57] ← '/';
  xchr[60] ← '0'; xchr[61] ← '1'; xchr[62] ← '2'; xchr[63] ← '3'; xchr[64] ← '4';
  xchr[65] ← '5'; xchr[66] ← '6'; xchr[67] ← '7';
  xchr[70] ← '8'; xchr[71] ← '9'; xchr[72] ← ':'; xchr[73] ← ';'; xchr[74] ← '<';
  xchr[75] ← '='; xchr[76] ← '>'; xchr[77] ← '?';
  xchr[100] ← '@'; xchr[101] ← 'A'; xchr[102] ← 'B'; xchr[103] ← 'C'; xchr[104] ← 'D';
  xchr[105] ← 'E'; xchr[106] ← 'F'; xchr[107] ← 'G';
  xchr[110] ← 'H'; xchr[111] ← 'I'; xchr[112] ← 'J'; xchr[113] ← 'K'; xchr[114] ← 'L';
  xchr[115] ← 'M'; xchr[116] ← 'N'; xchr[117] ← 'O';
  xchr[120] ← 'P'; xchr[121] ← 'Q'; xchr[122] ← 'R'; xchr[123] ← 'S'; xchr[124] ← 'T';
  xchr[125] ← 'U'; xchr[126] ← 'V'; xchr[127] ← 'W';
  xchr[130] ← 'X'; xchr[131] ← 'Y'; xchr[132] ← 'Z'; xchr[133] ← '['; xchr[134] ← '\';
  xchr[135] ← ']'; xchr[136] ← '^'; xchr[137] ← '_';
  xchr[140] ← '`'; xchr[141] ← 'a'; xchr[142] ← 'b'; xchr[143] ← 'c'; xchr[144] ← 'd';
  xchr[145] ← 'e'; xchr[146] ← 'f'; xchr[147] ← 'g';
  xchr[150] ← 'h'; xchr[151] ← 'i'; xchr[152] ← 'j'; xchr[153] ← 'k'; xchr[154] ← 'l';
  xchr[155] ← 'm'; xchr[156] ← 'n'; xchr[157] ← 'o';
  xchr[160] ← 'p'; xchr[161] ← 'q'; xchr[162] ← 'r'; xchr[163] ← 's'; xchr[164] ← 't';
  xchr[165] ← 'u'; xchr[166] ← 'v'; xchr[167] ← 'w';
  xchr[170] ← 'x'; xchr[171] ← 'y'; xchr[172] ← 'z'; xchr[173] ← '{'; xchr[174] ← '|';
  xchr[175] ← '}'; xchr[176] ← '~';
```

See also sections 23, 24, 74, 77, 80, 97, 118, 184, 233, 272, 276, 294, 309, 390, 409, 465, 507, 516, 547, 577, 582, 620, 623, 633, 677, 681, 688, 697, 709, 711, 724, 818, 828, 836, 859, 945, 1103, 1165, 1208, 1443, 1458, 1476, 1521, 1549, 1569, 1582, 1626, 1631, 1703, 1748, 1814, 1833, and 1857.

This code is used in section 8.

22. Some of the ASCII codes without visible characters have been given symbolic names in this program because they are used with a special meaning.

```
define null_code = '0' { ASCII code that might disappear }
define carriage_return = '15' { ASCII code used at end of line }
define invalid_code = '177' { ASCII code that many systems prohibit in text files }
```

23. The ASCII code is “standard” only to a certain extent, since many computer installations have found it advantageous to have ready access to more than 94 printing characters. Appendix C of *The TeXbook* gives a complete specification of the intended correspondence between characters and TeX’s internal representation.

If TeX is being used on a garden-variety Pascal for which only standard ASCII codes will appear in the input and output files, it doesn’t really matter what codes are specified in *xchr*[0 .. ’37], but the safest policy is to blank everything out by using the code shown below.

However, other settings of *xchr* will make TeX more friendly on computers that have an extended character set, so that users can type things like ‘≠’ instead of ‘\ne’. People with extended character sets can assign codes arbitrarily, giving an *xchr* equivalent to whatever characters the users of TeX are allowed to have in their input files. It is best to make the codes correspond to the intended interpretations as shown in Appendix C whenever possible; but this is not necessary. For example, in countries with an alphabet of more than 26 letters, it is usually best to map the additional letters into codes less than ’40. To get the most “permissive” character set, change ‘_’ on the right of these assignment statements to *chr*(*i*).

⟨Set initial values of key variables 21⟩ +≡

```
for i ← 0 to ’37 do xchr[i] ← ‘_’;
for i ← ’177 to ’377 do xchr[i] ← ‘_’;
```

24. The following system-independent code makes the *xord* array contain a suitable inverse to the information in *xchr*. Note that if *xchr*[*i*] = *xchr*[*j*] where *i* < *j* < ’177, the value of *xord*[*xchr*[*i*]] will turn out to be *j* or more; hence, standard ASCII code numbers will be used instead of codes below ’40 in case there is a coincidence.

⟨Set initial values of key variables 21⟩ +≡

```
for i ← first_text_char to last_text_char do xord[chr(i)] ← invalid_code;
for i ← ’200 to ’377 do xord[xchr[i]] ← i;
for i ← 0 to ’176 do xord[xchr[i]] ← i;
```

25. Input and output. The bane of portability is the fact that different operating systems treat input and output quite differently, perhaps because computer scientists have not given sufficient attention to this problem. People have felt somehow that input and output are not part of “real” programming. Well, it is true that some kinds of programming are more fun than others. With existing input/output conventions being so diverse and so messy, the only sources of joy in such parts of the code are the rare occasions when one can find a way to make the program a little less bad than it might have been. We have two choices, either to attack I/O now and get it over with, or to postpone I/O until near the end. Neither prospect is very attractive, so let’s get it over with.

The basic operations we need to do are (1) inputting and outputting of text, to or from a file or the user’s terminal; (2) inputting and outputting of eight-bit bytes, to or from a file; (3) instructing the operating system to initiate (“open”) or to terminate (“close”) input or output from a specified file; (4) testing whether the end of an input file has been reached.

TeX needs to deal with two kinds of files. We shall use the term *alpha_file* for a file that contains textual data, and the term *byte_file* for a file that contains eight-bit binary information. These two types turn out to be the same on many computers, but sometimes there is a significant distinction, so we shall be careful to distinguish between them. Standard protocols for transferring such files from computer to computer, via high-speed networks, are now becoming available to more and more communities of users.

The program actually makes use also of a third kind of file, called a *word_file*, when dumping and reloading base information for its own initialization. We shall define a word file later; but it will be possible for us to specify simple operations on word files before they are defined.

⟨Types in the outer block 18⟩ +≡

```
eight_bits = 0 .. 255; { unsigned one-byte quantity }
alpha_file = packed file of text_char; { files that contain textual data }
byte_file = packed file of eight_bits; { files that contain binary data }
```

26. Most of what we need to do with respect to input and output can be handled by the I/O facilities that are standard in Pascal, i.e., the routines called *get*, *put*, *eof*, and so on. But standard Pascal does not allow file variables to be associated with file names that are determined at run time, so it cannot be used to implement TeX; some sort of extension to Pascal’s ordinary *reset* and *rewrite* is crucial for our purposes. We shall assume that *name_of_file* is a variable of an appropriate type such that the Pascal run-time system being used to implement TeX can open a file whose external name is specified by *name_of_file*.

⟨Global variables 13⟩ +≡

```
name_of_file: packed array [1 .. file_name_size] of char;
    { on some systems this may be a record variable }
name_length: 0 .. file_name_size;
    { this many characters are actually relevant in name_of_file (the rest are blank) }
```

27. The Pascal-H compiler with which the present version of TEX was prepared has extended the rules of Pascal in a very convenient way. To open file f , we can write

```

reset( $f$ ,  $name$ ,  $\text{'}/0\text{'}$ )      for input;
rewrite( $f$ ,  $name$ ,  $\text{'}/0\text{'}$ )    for output.

```

The ‘ $name$ ’ parameter, which is of type ‘**packed array** [$\langle any \rangle$] **of** $char$ ’, stands for the name of the external file that is being opened for input or output. Blank spaces that might appear in $name$ are ignored.

The ‘ $/0$ ’ parameter tells the operating system not to issue its own error messages if something goes wrong. If a file of the specified name cannot be found, or if such a file cannot be opened for some other reason (e.g., someone may already be trying to write the same file), we will have $erstat(f) \neq 0$ after an unsuccessful *reset* or *rewrite*. This allows TEX to undertake appropriate corrective action.

TEX’s file-opening procedures return *false* if no file identified by $name_of_file$ could be opened.

```

define reset_OK( $\#$ )  $\equiv$   $erstat(\#) = 0$ 
define rewrite_OK( $\#$ )  $\equiv$   $erstat(\#) = 0$ 

function a_open_in(var  $f$  :  $alpha\_file$ ):  $boolean$ ; { open a text file for input }
  begin reset( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $a\_open\_in \leftarrow reset\_OK(f)$ ;
  end;

function a_open_out(var  $f$  :  $alpha\_file$ ):  $boolean$ ; { open a text file for output }
  begin rewrite( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $a\_open\_out \leftarrow rewrite\_OK(f)$ ;
  end;

function b_open_in(var  $f$  :  $byte\_file$ ):  $boolean$ ; { open a binary file for input }
  begin reset( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $b\_open\_in \leftarrow reset\_OK(f)$ ;
  end;

function b_open_out(var  $f$  :  $byte\_file$ ):  $boolean$ ; { open a binary file for output }
  begin rewrite( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $b\_open\_out \leftarrow rewrite\_OK(f)$ ;
  end;

function w_open_in(var  $f$  :  $word\_file$ ):  $boolean$ ; { open a word file for input }
  begin reset( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $w\_open\_in \leftarrow reset\_OK(f)$ ;
  end;

function w_open_out(var  $f$  :  $word\_file$ ):  $boolean$ ; { open a word file for output }
  begin rewrite( $f$ ,  $name\_of\_file$ ,  $\text{'}/0\text{'}$ );  $w\_open\_out \leftarrow rewrite\_OK(f)$ ;
  end;

```

28. Files can be closed with the Pascal-H routine ‘ $close(f)$ ’, which should be used when all input or output with respect to f has been completed. This makes f available to be opened again, if desired; and if f was used for output, the *close* operation makes the corresponding external file appear on the user’s area, ready to be read.

These procedures should not generate error messages if a file is being closed before it has been successfully opened.

```

procedure a_close(var  $f$  :  $alpha\_file$ ); { close a text file }
  begin close( $f$ );
  end;

procedure b_close(var  $f$  :  $byte\_file$ ); { close a binary file }
  begin close( $f$ );
  end;

procedure w_close(var  $f$  :  $word\_file$ ); { close a word file }
  begin close( $f$ );
  end;

```

29. Binary input and output are done with Pascal's ordinary *get* and *put* procedures, so we don't have to make any other special arrangements for binary I/O. Text output is also easy to do with standard Pascal routines. The treatment of text input is more difficult, however, because of the necessary translation to *ASCII_code* values. TeX's conventions should be efficient, and they should blend nicely with the user's operating environment.

30. Input from text files is read one line at a time, using a routine called *input_ln*. This function is defined in terms of global variables called *buffer*, *first*, and *last* that will be described in detail later; for now, it suffices for us to know that *buffer* is an array of *ASCII_code* values, and that *first* and *last* are indices into this array representing the beginning and ending of a line of text.

⟨Global variables 13⟩ +≡

buffer: **array** [0 .. *buf_size*] **of** *ASCII_code*; { lines of characters being read }

first: 0 .. *buf_size*; { the first unused position in *buffer* }

last: 0 .. *buf_size*; { end of the line just input to *buffer* }

max_buf_stack: 0 .. *buf_size*; { largest index used in *buffer* }

31. The *input_ln* function brings the next line of input from the specified file into available positions of the buffer array and returns the value *true*, unless the file has already been entirely read, in which case it returns *false* and sets $last \leftarrow first$. In general, the *ASCII_code* numbers that represent the next line of the file are input into $buffer[first]$, $buffer[first + 1]$, \dots , $buffer[last - 1]$; and the global variable *last* is set equal to *first* plus the length of the line. Trailing blanks are removed from the line; thus, either $last = first$ (in which case the line was entirely blank) or $buffer[last - 1] \neq "_"$.

An overflow error is given, however, if the normal actions of *input_ln* would make $last \geq buf_size$; this is done so that other parts of TeX can safely look at the contents of $buffer[last + 1]$ without overstepping the bounds of the *buffer* array. Upon entry to *input_ln*, the condition $first < buf_size$ will always hold, so that there is always room for an “empty” line.

The variable *max_buf_stack*, which is used to keep track of how large the *buf_size* parameter must be to accommodate the present job, is also kept up to date by *input_ln*.

If the *bypass_eoln* parameter is *true*, *input_ln* will do a *get* before looking at the first character of the line; this skips over an *eoln* that was in $f\uparrow$. The procedure does not do a *get* when it reaches the end of the line; therefore it can be used to acquire input from the user’s terminal as well as from ordinary text files.

Standard Pascal says that a file should have *eoln* immediately before *eof*, but TeX needs only a weaker restriction: If *eof* occurs in the middle of a line, the system function *eoln* should return a *true* result (even though $f\uparrow$ will be undefined).

Since the inner loop of *input_ln* is part of TeX’s “inner loop”—each character of input comes in at this place—it is wise to reduce system overhead by making use of special routines that read in an entire array of characters at once, if such routines are available. The following code uses standard Pascal to illustrate what needs to be done, but finer tuning is often possible at well-developed Pascal sites.

```
function input_ln(var f : alpha_file; bypass_eoln : boolean): boolean;
    { inputs the next line or returns false }
var last_nonblank: 0 .. buf_size; { last with trailing blanks removed }
begin if bypass_eoln then
    if  $\neg eof(f)$  then get(f); { input the first character of the line into  $f\uparrow$  }
    last  $\leftarrow first$ ; { cf. Matthew 19:30 }
if eof(f) then input_ln  $\leftarrow false$ 
else begin last_nonblank  $\leftarrow first$ ;
    while  $\neg eoln(f)$  do
        begin if  $last \geq max\_buf\_stack$  then
            begin max_buf_stack  $\leftarrow last + 1$ ;
            if  $max\_buf\_stack = buf\_size$  then (Report overflow of the input buffer, and abort 35);
            end;
            buffer[last]  $\leftarrow xord[f\uparrow]$ ; get(f); incr(last);
            if buffer[last - 1]  $\neq "\_"$  then last_nonblank  $\leftarrow last$ ;
            end;
        last  $\leftarrow last\_nonblank$ ; input_ln  $\leftarrow true$ ;
    end;
end;
```

32. The user’s terminal acts essentially like other files of text, except that it is used both for input and for output. When the terminal is considered an input file, the file variable is called *term_in*, and when it is considered an output file the file variable is *term_out*.

```
<Global variables 13> +≡
term_in: alpha_file; { the terminal as an input file }
term_out: alpha_file; { the terminal as an output file }
```

33. Here is how to open the terminal files in Pascal-H. The ‘/I’ switch suppresses the first *get*.

```
define t_open_in  $\equiv$  reset(term_in, ‘TTY:’, ‘/O/I’) { open the terminal for text input }
define t_open_out  $\equiv$  rewrite(term_out, ‘TTY:’, ‘/O’) { open the terminal for text output }
```

34. Sometimes it is necessary to synchronize the input/output mixture that happens on the user’s terminal, and three system-dependent procedures are used for this purpose. The first of these, *update_terminal*, is called when we want to make sure that everything we have output to the terminal so far has actually left the computer’s internal buffers and been sent. The second, *clear_terminal*, is called when we wish to cancel any input that the user may have typed ahead (since we are about to issue an unexpected error message). The third, *wake_up_terminal*, is supposed to revive the terminal if the user has disabled it by some instruction to the operating system. The following macros show how these operations can be specified in Pascal-H:

```
define update_terminal  $\equiv$  break(term_out) { empty the terminal output buffer }
define clear_terminal  $\equiv$  break_in(term_in, true) { clear the terminal input buffer }
define wake_up_terminal  $\equiv$  do_nothing { cancel the user’s cancellation of output }
```

35. We need a special routine to read the first line of T_EX input from the user’s terminal. This line is different because it is read before we have opened the transcript file; there is sort of a “chicken and egg” problem here. If the user types ‘\input paper’ on the first line, or if some macro invoked by that line does such an \input, the transcript file will be named ‘paper.log’; but if no \input commands are performed during the first line of terminal input, the transcript file will acquire its default name ‘texput.log’. (The transcript file will not contain error messages generated by the first line before the first \input command.)

The first line is even more special if we are lucky enough to have an operating system that treats T_EX differently from a run-of-the-mill Pascal object program. It’s nice to let the user start running a T_EX job by typing a command line like ‘tex paper’; in such a case, T_EX will operate as if the first line of input were ‘paper’, i.e., the first line will consist of the remainder of the command line, after the part that invoked T_EX.

The first line is special also because it may be read before T_EX has input a format file. In such cases, normal error messages cannot yet be given. The following code uses concepts that will be explained later. (If the Pascal compiler does not support non-local **goto**, the statement ‘goto final_end’ should be replaced by something that quietly terminates the program.)

```
<Report overflow of the input buffer, and abort 35>  $\equiv$ 
if format_ident = 0 then
  begin write_ln(term_out, ‘Buffer_size_exceeded!’); goto final_end;
  end
else begin cur_input.loc_field  $\leftarrow$  first; cur_input.limit_field  $\leftarrow$  last - 1;
  overflow(“buffer_size”, buf_size);
end
```

This code is used in sections 31 and 1753.

36. Different systems have different ways to get started. But regardless of what conventions are adopted, the routine that initializes the terminal should satisfy the following specifications:

- 1) It should open file *term_in* for input from the terminal. (The file *term_out* will already be open for output to the terminal.)
- 2) If the user has given a command line, this line should be considered the first line of terminal input. Otherwise the user should be prompted with ‘**’, and the first line of input should be whatever is typed in response.
- 3) The first line of input, which might or might not be a command line, should appear in locations *first* to *last* – 1 of the *buffer* array.
- 4) The global variable *loc* should be set so that the character to be read next by TEX is in *buffer[loc]*. This character should not be blank, and we should have *loc* < *last*.

(It may be necessary to prompt the user several times before a non-blank line comes in. The prompt is ‘**’ instead of the later ‘*’ because the meaning is slightly different: ‘\input’ need not be typed immediately after ‘**’.)

define *loc* \equiv *cur_input.loc_field* { location of first unread character in *buffer* }

37. The following program does the required initialization without retrieving a possible command line. It should be clear how to modify this routine to deal with command lines, if the system permits them.

```
function init_terminal: boolean; { gets the terminal input started }
  label exit;
  begin t_open_in;
  loop begin wake_up_terminal; write(term_out, ‘**’); update_terminal;
    if  $\neg$ input_ln(term_in, true) then { this shouldn’t happen }
      begin write_ln(term_out); write(term_out, ‘!_End_of_file_on_the_terminal...why?’);
        init_terminal  $\leftarrow$  false; return;
      end;
    loc  $\leftarrow$  first;
    while (loc < last)  $\wedge$  (buffer[loc] = “_”) do incr(loc);
    if loc < last then
      begin init_terminal  $\leftarrow$  true; return; { return unless the line was all blank }
      end;
    write_ln(term_out, ‘Please_type_the_name_of_your_input_file.’);
  end;
exit: end;
```

38. String handling. Control sequence names and diagnostic messages are variable-length strings of eight-bit characters. Since Pascal does not have a well-developed string mechanism, TeX does all of its string processing by homegrown methods.

Elaborate facilities for dynamic strings are not needed, so all of the necessary operations can be handled with a simple data structure. The array *str_pool* contains all of the (eight-bit) ASCII codes in all of the strings, and the array *str_start* contains indices of the starting points of each string. Strings are referred to by integer numbers, so that string number *s* comprises the characters *str_pool*[*j*] for *str_start*[*s*] ≤ *j* < *str_start*[*s* + 1]. Additional integer variables *pool_ptr* and *str_ptr* indicate the number of entries used so far in *str_pool* and *str_start*, respectively; locations *str_pool*[*pool_ptr*] and *str_start*[*str_ptr*] are ready for the next string to be allocated.

String numbers 0 to 255 are reserved for strings that correspond to single ASCII characters. This is in accordance with the conventions of WEB, which converts single-character strings into the ASCII code number of the single character involved, while it converts other strings into integers and builds a string pool file. Thus, when the string constant "." appears in the program below, WEB converts it into the integer 46, which is the ASCII code for a period, while WEB will convert a string like "hello" into some integer greater than 255. String number 46 will presumably be the single character '.'; but some ASCII codes have no standard visible representation, and TeX sometimes needs to be able to print an arbitrary ASCII character, so the first 256 strings are used to specify exactly what should be printed for each of the 256 possibilities.

Elements of the *str_pool* array must be ASCII codes that can actually be printed; i.e., they must have an *xchr* equivalent in the local character set. (This restriction applies only to preloaded strings, not to those generated dynamically by the user.)

Some Pascal compilers won't pack integers into a single byte unless the integers lie in the range −128 .. 127. To accommodate such systems we access the string pool only via macros that can easily be redefined.

```
define si(#) ≡ # { convert from ASCII_code to packed_ASCII_code }
define so(#) ≡ # { convert from packed_ASCII_code to ASCII_code }

⟨Types in the outer block 18⟩ +≡
  pool_pointer = 0 .. pool_size; { for variables that point into str_pool }
  str_number = 0 .. max_strings; { for variables that point into str_start }
  packed_ASCII_code = 0 .. 255; { elements of str_pool array }
```

39. ⟨Global variables 13⟩ +≡

```
str_pool: packed array [pool_pointer] of packed_ASCII_code; { the characters }
str_start: array [str_number] of pool_pointer; { the starting pointers }
pool_ptr: pool_pointer; { first unused position in str_pool }
str_ptr: str_number; { number of the current string being created }
init_pool_ptr: pool_pointer; { the starting value of pool_ptr }
init_str_ptr: str_number; { the starting value of str_ptr }
```

40. Several of the elementary string operations are performed using WEB macros instead of Pascal procedures, because many of the operations are done quite frequently and we want to avoid the overhead of procedure calls. For example, here is a simple macro that computes the length of a string.

```
define length(#) ≡ (str_start[# + 1] − str_start[#]) { the number of characters in string number # }
```

41. The length of the current string is called *cur_length*:

```
define cur_length ≡ (pool_ptr − str_start[str_ptr])
```

42. Strings are created by appending character codes to *str_pool*. The *append_char* macro, defined here, does not check to see if the value of *pool_ptr* has gotten too high; this test is supposed to be made before *append_char* is used. There is also a *flush_char* macro, which erases the last character appended.

To test if there is room to append *l* more characters to *str_pool*, we shall write *str_room(l)*, which aborts TeX and gives an apologetic error message if there isn't enough room.

```

define append_char(#) ≡ { put ASCII_code # at the end of str_pool }
    begin str_pool[pool_ptr] ← si(#); incr(pool_ptr);
    end
define flush_char ≡ decr(pool_ptr) { forget the last character in the pool }
define str_room(#) ≡ { make sure that the pool hasn't overflowed }
    begin if pool_ptr + # > pool_size then overflow("pool_size", pool_size − init_pool_ptr);
    end

```

43. Once a sequence of characters has been appended to *str_pool*, it officially becomes a string when the function *make_string* is called. This function returns the identification number of the new string as its value.

```

function make_string: str_number; { current string enters the pool }
    begin if str_ptr = max_strings then overflow("number_of_strings", max_strings − init_str_ptr);
    incr(str_ptr); str_start[str_ptr] ← pool_ptr; make_string ← str_ptr − 1;
    end;

```

44. To destroy the most recently made string, we say *flush_string*.

```

define flush_string ≡
    begin decr(str_ptr); pool_ptr ← str_start[str_ptr];
    end

```

45. The following subroutine compares string *s* with another string of the same length that appears in *buffer* starting at position *k*; the result is *true* if and only if the strings are equal. Empirical tests indicate that *str_eq_buf* is used in such a way that it tends to return *true* about 80 percent of the time.

```

function str_eq_buf(s : str_number; k : integer): boolean; { test equality of strings }
    label not_found; { loop exit }
    var j: pool_pointer; { running index }
        result: boolean; { result of comparison }
    begin j ← str_start[s];
    while j < str_start[s + 1] do
        begin if so(str_pool[j]) ≠ buffer[k] then
            begin result ← false; goto not_found;
            end;
        incr(j); incr(k);
        end;
    result ← true;
    not_found: str_eq_buf ← result;
    end;

```

46. Here is a similar routine, but it compares two strings in the string pool, and it does not assume that they have the same length.

```
function str_eq_str(s, t : str_number): boolean; { test equality of strings }
  label not_found; { loop exit }
  var j, k: pool_pointer; { running indices }
      result: boolean; { result of comparison }
  begin result  $\leftarrow$  false;
  if length(s)  $\neq$  length(t) then goto not_found;
  j  $\leftarrow$  str_start[s]; k  $\leftarrow$  str_start[t];
  while j < str_start[s + 1] do
    begin if str_pool[j]  $\neq$  str_pool[k] then goto not_found;
      incr(j); incr(k);
    end;
  result  $\leftarrow$  true;
not_found: str_eq_str  $\leftarrow$  result;
end;
```

47. The initial values of *str_pool*, *str_start*, *pool_ptr*, and *str_ptr* are computed by the INITEX program, based in part on the information that WEB has output while processing TEX.

```
init function get_strings_started: boolean;
  { initializes the string pool, but returns false if something goes wrong }
label done, exit;
var k, l: 0 .. 255; { small indices or counters }
    m, n: text_char; { characters input from pool_file }
    g: str_number; { garbage }
    a: integer; { accumulator for check sum }
    c: boolean; { check sum has been checked }
begin pool_ptr  $\leftarrow$  0; str_ptr  $\leftarrow$  0; str_start[0]  $\leftarrow$  0; < Make the first 256 strings 48 >;
  < Read the other strings from the TEX.POOL file and return true, or give an error message and return
    false 51 >;
exit: end;
tini
```

48. **define** *app_lc_hex*(#) \equiv *l* \leftarrow #;
 if *l* < 10 **then** *append_char*(*l* + "0") **else** *append_char*(*l* - 10 + "a")

< Make the first 256 strings 48 > \equiv

```
for k  $\leftarrow$  0 to 255 do
  begin if ((Character k cannot be printed 49)) then
    begin append_char("^"); append_char("^");
    if k < '100 then append_char(k + '100)
    else if k < '200 then append_char(k - '100)
      else begin app_lc_hex(k div 16); app_lc_hex(k mod 16);
        end;
      end
    else append_char(k);
    g  $\leftarrow$  make_string;
  end
```

This code is used in section 47.

49. The first 128 strings will contain 95 standard ASCII characters, and the other 33 characters will be printed in three-symbol form like ‘ \sim A’ unless a system-dependent change is made here. Installations that have an extended character set, where for example $xchr[‘32] = ‘\#$, would like string ‘32 to be the single character ‘32 instead of the three characters ‘136, ‘136, ‘132 (\sim Z). On the other hand, even people with an extended character set will want to represent string ‘15 by \sim M, since ‘15 is *carriage_return*; the idea is to produce visible strings instead of tabs or line-feeds or carriage-returns or bell-rings or characters that are treated anomalously in text files.

Unprintable characters of codes 128–255 are, similarly, rendered \sim 80– \sim ff.

The boolean expression defined here should be *true* unless TEX internal code number k corresponds to a non-troublesome visible symbol in the local character set. An appropriate formula for the extended character set recommended in *The TEXbook* would, for example, be ‘ $k \in [0, ‘10 \dots ‘12, ‘14, ‘15, ‘33, ‘177 \dots ‘377]$ ’. If character k cannot be printed, and $k < ‘200$, then character $k + ‘100$ or $k - ‘100$ must be printable; moreover, ASCII codes [‘41 .. ‘46, ‘60 .. ‘71, ‘136, ‘141 .. ‘146, ‘160 .. ‘171] must be printable. Thus, at least 80 printable characters are needed.

⟨Character k cannot be printed 49⟩ \equiv
 $(k < \text{"_"}) \vee (k > \text{"~"})$

This code is used in section 48.

50. When the WEB system program called TANGLE processes the TEX.WEB description that you are now reading, it outputs the Pascal program TEX.PAS and also a string pool file called TEX.POOL. The INITEX program reads the latter file, where each string appears as a two-digit decimal length followed by the string itself, and the information is recorded in TEX’s string memory.

⟨Global variables 13⟩ $+\equiv$
init *pool_file*: *alpha_file*; { the string-pool file output by TANGLE }
tini

51. **define** *bad_pool*(#) \equiv
 begin *wake_up_terminal*; *write_ln*(*term_out*, #); *a_close*(*pool_file*); *get_strings_started* \leftarrow *false*;
 return;
 end

⟨Read the other strings from the TEX.POOL file and return *true*, or give an error message and return *false* 51⟩ \equiv
 name_of_file \leftarrow *pool_name*; { we needn’t set *name_length* }
 if *a_open_in*(*pool_file*) **then**
 begin *c* \leftarrow *false*;
 repeat ⟨Read one string, but return *false* if the string memory space is getting too tight for comfort 52⟩;
 until *c*;
 a_close(*pool_file*); *get_strings_started* \leftarrow *true*;
 end
 else *bad_pool*(‘!_I_can’t_read_TEX.POOL.’)

This code is used in section 47.

52. \langle Read one string, but return *false* if the string memory space is getting too tight for comfort 52 $\rangle \equiv$

```

begin if eof(pool_file) then bad_pool(`!TEX.POOL_has_no_check_sum.`);
read(pool_file, m, n); { read two digits of string length }
if m = `` then  $\langle$  Check the pool check sum 53  $\rangle$ 
else begin if (xord[m] < "0")  $\vee$  (xord[m] > "9")  $\vee$  (xord[n] < "0")  $\vee$  (xord[n] > "9") then
  bad_pool(`!TEX.POOL_line_doesn't_begin_with_two_digits.`);
  l  $\leftarrow$  xord[m] * 10 + xord[n] - "0" * 11; { compute the length }
if pool_ptr + l + string_vacancies > pool_size then bad_pool(`!You_have_to_increase_POOLSIZE.`);
for k  $\leftarrow$  1 to l do
  begin if eoln(pool_file) then m  $\leftarrow$  ` ` else read(pool_file, m);
  append_char(xord[m]);
end;
read_ln(pool_file); g  $\leftarrow$  make_string;
end;
end

```

This code is used in section 51.

53. The WEB operation @ $\$$ denotes the value that should be at the end of this TEX.POOL file; any other value means that the wrong pool file has been loaded.

\langle Check the pool check sum 53 $\rangle \equiv$

```

begin a  $\leftarrow$  0; k  $\leftarrow$  1;
loop begin if (xord[n] < "0")  $\vee$  (xord[n] > "9") then
  bad_pool(`!TEX.POOL_check_sum_doesn't_have_nine_digits.`);
  a  $\leftarrow$  10 * a + xord[n] - "0";
  if k = 9 then goto done;
  incr(k); read(pool_file, n);
end;
done: if a  $\neq$  @ $\$$  then bad_pool(`!TEX.POOL_doesn't_match;TANGLE_me_again.`);
  c  $\leftarrow$  true;
end

```

This code is used in section 52.

54. On-line and off-line printing. Messages that are sent to a user's terminal and to the transcript-log file are produced by several '*print*' procedures. These procedures will direct their output to a variety of places, based on the setting of the global variable *selector*, which has the following possible values:

term_and_log, the normal setting, prints on the terminal and on the transcript file.

log_only, prints only on the transcript file.

term_only, prints only on the terminal.

no_print, doesn't print at all. This is used only in rare cases before the transcript file is open.

pseudo, puts output into a cyclic buffer that is used by the *show_context* routine; when we get to that routine we shall discuss the reasoning behind this curious mode.

new_string, appends the output to the current string in the string pool.

0 to 15, prints on one of the sixteen files for `\write` output.

The symbolic names '*term_and_log*', etc., have been assigned numeric codes that satisfy the convenient relations $no_print + 1 = term_only$, $no_print + 2 = log_only$, $term_only + 2 = log_only + 1 = term_and_log$.

Three additional global variables, *tally* and *term_offset* and *file_offset*, record the number of characters that have been printed since they were most recently cleared to zero. We use *tally* to record the length of (possibly very long) stretches of printing; *term_offset* and *file_offset*, on the other hand, keep track of how many characters have appeared so far on the current line that has been output to the terminal or to the transcript file, respectively.

```
define no_print = 16 { selector setting that makes data disappear }
define term_only = 17 { printing is destined for the terminal only }
define log_only = 18 { printing is destined for the transcript file only }
define term_and_log = 19 { normal selector setting }
define pseudo = 20 { special selector setting for show_context }
define new_string = 21 { printing is deflected to the string pool }
define max_selector = 21 { highest selector setting }
```

⟨Global variables 13⟩ +≡

log_file: *alpha_file*; { transcript of TeX session }

selector: 0 .. *max_selector*; { where to print a message }

dig: **array** [0 .. 22] **of** 0 .. 15; { digits in a number being output }

tally: *integer*; { the number of characters recently printed }

term_offset: 0 .. *max_print_line*; { the number of characters on the current terminal line }

file_offset: 0 .. *max_print_line*; { the number of characters on the current file line }

trick_buf: **array** [0 .. *error_line*] **of** *ASCII_code*; { circular buffer for pseudoprinting }

trick_count: *integer*; { threshold for pseudoprinting, explained later }

first_count: *integer*; { another variable for pseudoprinting }

55. ⟨Initialize the output routines 55⟩ ≡

selector ← *term_only*; *tally* ← 0; *term_offset* ← 0; *file_offset* ← 0;

See also sections 61, 554, and 559.

This code is used in section 1510.

56. Macro abbreviations for output to the terminal and to the log file are defined here for convenience. Some systems need special conventions for terminal output, and it is possible to adhere to those conventions by changing *wterm*, *wterm_ln*, and *wterm_cr* in this section.

```
define wterm(#) ≡ write(term_out,#)
define wterm_ln(#) ≡ write_ln(term_out,#)
define wterm_cr ≡ write_ln(term_out)
define wlog(#) ≡ write(log_file,#)
define wlog_ln(#) ≡ write_ln(log_file,#)
define wlog_cr ≡ write_ln(log_file)
```

57. To end a line of text output, we call *print_ln*.

⟨Basic printing procedures 57⟩ ≡

```
procedure print_ln; { prints an end-of-line }
begin case selector of
  term_and_log: begin wterm_cr; wlog_cr; term_offset ← 0; file_offset ← 0;
    end;
  log_only: begin wlog_cr; file_offset ← 0;
    end;
  term_only: begin wterm_cr; term_offset ← 0;
    end;
  no_print, pseudo, new_string: do_nothing;
othercases write_ln(write_file[selector])
endcases;
end; { tally is not affected }
```

See also sections 58, 59, 60, 62, 63, 64, 65, 284, 285, 544, 873, 1599, and 1819.

This code is used in section 4.

58. The *print_char* procedure sends one character to the desired destination, using the *xchr* array to map it into an external character compatible with *input_ln*. All printing comes through *print_ln* or *print_char*.

⟨Basic printing procedures 57⟩ +≡

```
procedure print_char(s : ASCII_code); { prints a single character }
  label exit;
  begin if ⟨Character s is the current new-line character 262⟩ then
    if selector < pseudo then
      begin print_ln; return;
    end;
  case selector of
    term_and_log: begin wterm(xchr[s]); wlog(xchr[s]); incr(term_offset); incr(file_offset);
      if term_offset = max_print_line then
        begin wterm_cr; term_offset ← 0;
        end;
      if file_offset = max_print_line then
        begin wlog_cr; file_offset ← 0;
        end;
      end;
    log_only: begin wlog(xchr[s]); incr(file_offset);
      if file_offset = max_print_line then print_ln;
      end;
    term_only: begin wterm(xchr[s]); incr(term_offset);
      if term_offset = max_print_line then print_ln;
      end;
    no_print: do_nothing;
    pseudo: if tally < trick_count then trick_buf[tally mod error_line] ← s;
    new_string: begin if pool_ptr < pool_size then append_char(s);
      end; { we drop characters if the string space is full }
    othercases write(write_file[selector], xchr[s])
    endcases;
    incr(tally);
  exit: end;
```

59. An entire string is output by calling *print*. Note that if we are outputting the single standard ASCII character *c*, we could call *print*("c"), since "c" = 99 is the number of a single-character string, as explained above. But *print_char*("c") is quicker, so TEX goes directly to the *print_char* routine when it knows that this is safe. (The present implementation assumes that it is always safe to print a visible ASCII character.)

⟨Basic printing procedures 57⟩ +≡

```
procedure print(s : integer); { prints string s }
  label exit;
  var j: pool_pointer; { current character code position }
      nl: integer; { new-line character to restore }
  begin if s ≥ str_ptr then s ← "???" { this can't happen }
  else if s < 256 then
    if s < 0 then s ← "???" { can't happen }
    else begin if selector > pseudo then
      begin print_char(s); return; { internal strings are not expanded }
    end;
    if (⟨Character s is the current new-line character 262⟩) then
      if selector < pseudo then
        begin print_ln; return;
      end;
      nl ← new_line_char; new_line_char ← -1; { temporarily disable new-line character }
      j ← str_start[s];
      while j < str_start[s + 1] do
        begin print_char(so(str_pool[j])); incr(j);
        end;
      new_line_char ← nl; return;
    end;
    j ← str_start[s];
    while j < str_start[s + 1] do
      begin print_char(so(str_pool[j])); incr(j);
      end;
  exit: end;
```

60. Control sequence names, file names, and strings constructed with `\string` might contain *ASCII_code* values that can't be printed using *print_char*. Therefore we use *slow_print* for them:

⟨Basic printing procedures 57⟩ +≡

```
procedure slow_print(s : integer); { prints string s }
  var j: pool_pointer; { current character code position }
  begin if (s ≥ str_ptr) ∨ (s < 256) then print(s)
  else begin j ← str_start[s];
    while j < str_start[s + 1] do
      begin print(so(str_pool[j])); incr(j);
      end;
    end;
  end;
```

61. Here is the very first thing that T_EX prints: a headline that identifies the version number and format package. The *term_offset* variable is temporarily incorrect, but the discrepancy is not serious since we assume that this part of the program is system dependent.

⟨Initialize the output routines 55⟩ +≡

```
wterm(banner);
if format_ident = 0 then wterm_ln(`_(no_format_preloaded)`)
else begin slow_print(format_ident); print_ln;
end;
update_terminal;
```

62. The procedure *print_nl* is like *print*, but it makes sure that the string appears at the beginning of a new line.

⟨Basic printing procedures 57⟩ +≡

```
procedure print_nl(s : str_number); { prints string s at beginning of line }
begin if ((term_offset > 0) ∧ (odd(selector))) ∨ ((file_offset > 0) ∧ (selector ≥ log_only)) then print_ln;
print(s);
end;
```

63. The procedure *print_esc* prints a string that is preceded by the user's escape character (which is usually a backslash).

⟨Basic printing procedures 57⟩ +≡

```
procedure print_esc(s : str_number); { prints escape character, then s }
var c : integer; { the escape character code }
begin ⟨Set variable c to the current escape character 261⟩;
if c ≥ 0 then
  if c < 256 then print(c);
  slow_print(s);
end;
```

64. An array of digits in the range 0 .. 15 is printed by *print_the_digs*.

⟨Basic printing procedures 57⟩ +≡

```
procedure print_the_digs(k : eight_bits); { prints dig[k − 1] ... dig[0] }
begin while k > 0 do
  begin decr(k);
  if dig[k] < 10 then print_char("0" + dig[k])
  else print_char("A" − 10 + dig[k]);
  end;
end;
```

65. The following procedure, which prints out the decimal representation of a given integer n , has been written carefully so that it works properly if $n = 0$ or if $(-n)$ would cause overflow. It does not apply **mod** or **div** to negative arguments, since such operations are not implemented consistently by all Pascal compilers.

(Basic printing procedures 57) \equiv

```
procedure print_int( $n$  : longinteger); { prints an integer in decimal form }
  var  $k$ : 0 .. 23; { index to current digit; we assume that  $|n| < 10^{23}$  }
       $m$ : longinteger; { used to negate  $n$  in possibly dangerous cases }
  begin  $k \leftarrow 0$ ;
  if  $n < 0$  then
    begin print_char("-");
    if  $n > -1000000000$  then negate( $n$ )
    else begin  $m \leftarrow -1 - n$ ;  $n \leftarrow m \text{ div } 10$ ;  $m \leftarrow (m \text{ mod } 10) + 1$ ;  $k \leftarrow 1$ ;
      if  $m < 10$  then  $dig[0] \leftarrow m$ 
      else begin  $dig[0] \leftarrow 0$ ; incr( $n$ );
        end;
      end;
    end;
  repeat  $dig[k] \leftarrow n \text{ mod } 10$ ;  $n \leftarrow n \text{ div } 10$ ; incr( $k$ );
  until  $n = 0$ ;
  print_the_digs( $k$ );
end;
```

66. Here is a trivial procedure to print two digits; it is usually called with a parameter in the range $0 \leq n \leq 99$.

```
procedure print_two( $n$  : integer); { prints two least significant digits }
  begin  $n \leftarrow \text{abs}(n) \text{ mod } 100$ ; print_char("0" + ( $n \text{ div } 10$ )); print_char("0" + ( $n \text{ mod } 10$ ));
  end;
```

67. Hexadecimal printing of nonnegative integers is accomplished by *print_hex*.

```
procedure print_hex( $n$  : integer); { prints a positive integer in hexadecimal form }
  var  $k$ : 0 .. 22; { index to current digit; we assume that  $0 \leq n < 16^{22}$  }
  begin  $k \leftarrow 0$ ; print_char("");
  repeat  $dig[k] \leftarrow n \text{ mod } 16$ ;  $n \leftarrow n \text{ div } 16$ ; incr( $k$ );
  until  $n = 0$ ;
  print_the_digs( $k$ );
end;
```

68. Old versions of TeX needed a procedure called *print_ASCII* whose function is now subsumed by *print*. We retain the old name here as a possible aid to future software archaeologists.

```
define print_ASCII  $\equiv$  print
```

69. Roman numerals are produced by the *print_roman_int* routine. Readers who like puzzles might enjoy trying to figure out how this tricky code works; therefore no explanation will be given. Notice that 1990 yields *mcmxc*, not *mxm*.

```

procedure print_roman_int(n : integer);
  label exit;
  var j, k: pool_pointer; { mysterious indices into str_pool }
      u, v: nonnegative_integer; { mysterious numbers }
  begin j ← str_start["m2d5c2l5x2v5i"]; v ← 1000;
  loop begin while n ≥ v do
    begin print_char(so(str_pool[j])); n ← n − v;
    end;
    if n ≤ 0 then return; { nonpositive input produces no output }
    k ← j + 2; u ← v div (so(str_pool[k − 1]) − "0");
    if str_pool[k − 1] = si("2") then
      begin k ← k + 2; u ← u div (so(str_pool[k − 1]) − "0");
      end;
    if n + u ≥ v then
      begin print_char(so(str_pool[k])); n ← n + u;
      end
    else begin j ← j + 2; v ← v div (so(str_pool[j − 1]) − "0");
    end;
  end;
exit: end;

```

70. The *print* subroutine will not print a string that is still being created. The following procedure will.

```

procedure print_current_string; { prints a yet-unmade string }
  var j: pool_pointer; { points to current character code }
  begin j ← str_start[str_ptr];
  while j < pool_ptr do
    begin print_char(so(str_pool[j])); incr(j);
    end;
  end;

```

71. Here is a procedure that asks the user to type a line of input, assuming that the *selector* setting is either *term_only* or *term_and_log*. The input is placed into locations *first* through *last* − 1 of the *buffer* array, and echoed on the transcript file if appropriate.

This procedure is never called when *interaction* < *scroll_mode*.

```

define prompt_input(#) ≡
  begin wake_up_terminal; print(#); term_input;
  end { prints a string and gets a line of input }
procedure term_input; { gets a line from the terminal }
  var k: 0 .. buf_size; { index into buffer }
  begin update_terminal; { now the user sees the prompt for sure }
  if ¬input_ln(term_in, true) then fatal_error("End_of_file_on_the_terminal!");
  term_offset ← 0; { the user's line ended with ⟨return⟩ }
  decr(selector); { prepare to echo the input }
  if last ≠ first then
    for k ← first to last − 1 do print(buffer[k]);
  print_ln; incr(selector); { restore previous status }
  end;

```

72. Reporting errors. When something anomalous is detected, TeX typically does something like this:

```
print_err("Something_anomalous_has_been_detected");
help3("This_is_the_first_line_of_my_offer_to_help.")
("This_is_the_second_line. I'm_trying_to")
("explain_the_best_way_for_you_to_proceed.");
error;
```

A two-line help message would be given using *help2*, etc.; these informal helps should use simple vocabulary that complements the words used in the official error message that was printed. (Outside the U.S.A., the help messages should preferably be translated into the local vernacular. Each line of help is at most 60 characters long, in the present implementation, so that *max_print_line* will not be exceeded.)

The *print_err* procedure supplies a ‘!’ before the official message, and makes sure that the terminal is awake if a stop is going to occur. The *error* procedure supplies a ‘.’ after the official message, then it shows the location of the error; and if *interaction* = *error_stop_mode*, it also enters into a dialog with the user, during which time the help message may be printed.

73. The global variable *interaction* has four settings, representing increasing amounts of user interaction:

```
define batch_mode = 0 { omits all stops and omits terminal output }
define nonstop_mode = 1 { omits all stops }
define scroll_mode = 2 { omits error stops }
define error_stop_mode = 3 { stops at every opportunity to interact }
define print_err(#) ≡
  begin if interaction = error_stop_mode then wake_up_terminal;
  print_nl("! "); print(#);
end
```

⟨Global variables 13⟩ +≡

interaction: *batch_mode* .. *error_stop_mode*; { current level of interaction }

74. ⟨Set initial values of key variables 21⟩ +≡

interaction ← *error_stop_mode*;

75. TeX is careful not to call *error* when the print *selector* setting might be unusual. The only possible values of *selector* at the time of error messages are

no_print (when *interaction* = *batch_mode* and *log_file* not yet open);
term_only (when *interaction* > *batch_mode* and *log_file* not yet open);
log_only (when *interaction* = *batch_mode* and *log_file* is open);
term_and_log (when *interaction* > *batch_mode* and *log_file* is open).

⟨Initialize the print *selector* based on *interaction* 75⟩ ≡

if *interaction* = *batch_mode* **then** *selector* ← *no_print* **else** *selector* ← *term_only*

This code is used in sections 1441 and 1515.

76. A global variable *deletions_allowed* is set *false* if the *get_next* routine is active when *error* is called; this ensures that *get_next* and related routines like *get_token* will never be called recursively. A similar interlock is provided by *set_box_allowed*.

The global variable *history* records the worst level of error that has been detected. It has four possible values: *spotless*, *warning_issued*, *error_message_issued*, and *fatal_error_stop*.

Another global variable, *error_count*, is increased by one when an *error* occurs without an interactive dialog, and it is reset to zero at the end of every paragraph. If *error_count* reaches 100, T_EX decides that there is no point in continuing further.

```
define spotless = 0 { history value when nothing has been amiss yet }
define warning_issued = 1 { history value when begin_diagnostic has been called }
define error_message_issued = 2 { history value when error has been called }
define fatal_error_stop = 3 { history value when termination was premature }
```

⟨Global variables 13⟩ +≡

```
deletions_allowed: boolean; { is it safe for error to call get_token? }
set_box_allowed: boolean; { is it safe to do a \setbox assignment? }
history: spotless .. fatal_error_stop; { has the source input been clean so far? }
error_count: -1 .. 100; { the number of scrolled errors since the last paragraph ended }
```

77. The value of *history* is initially *fatal_error_stop*, but it will be changed to *spotless* if T_EX survives the initialization process.

⟨Set initial values of key variables 21⟩ +≡

```
deletions_allowed ← true; set_box_allowed ← true; error_count ← 0; { history is initialized elsewhere }
```

78. Since errors can be detected almost anywhere in T_EX, we want to declare the error procedures near the beginning of the program. But the error procedures in turn use some other procedures, which need to be declared *forward* before we get to *error* itself.

It is possible for *error* to be called recursively if some error arises when *get_token* is being used to delete a token, and/or if some fatal error occurs while T_EX is trying to fix a non-fatal one. But such recursion is never more than two levels deep.

⟨Error handling procedures 78⟩ ≡

```
procedure normalize_selector; forward;
procedure get_token; forward;
procedure term_input; forward;
procedure show_context; forward;
procedure begin_file_reading; forward;
procedure open_log_file; forward;
procedure close_files_and_terminate; forward;
procedure clear_for_error_prompt; forward;
procedure give_err_help; forward;
debug procedure debug_help; forward; gubed
```

See also sections 81, 82, 93, 94, and 95.

This code is used in section 4.

79. Individual lines of help are recorded in the array *help_line*, which contains entries in positions 0 .. (*help_ptr* - 1). They should be printed in reverse order, i.e., with *help_line*[0] appearing last.

```

define hlp1 (#)  $\equiv$  help_line[0]  $\leftarrow$  #; end
define hlp2 (#)  $\equiv$  help_line[1]  $\leftarrow$  #; hlp1
define hlp3 (#)  $\equiv$  help_line[2]  $\leftarrow$  #; hlp2
define hlp4 (#)  $\equiv$  help_line[3]  $\leftarrow$  #; hlp3
define hlp5 (#)  $\equiv$  help_line[4]  $\leftarrow$  #; hlp4
define hlp6 (#)  $\equiv$  help_line[5]  $\leftarrow$  #; hlp5
define help0  $\equiv$  help_ptr  $\leftarrow$  0 { sometimes there might be no help }
define help1  $\equiv$  begin help_ptr  $\leftarrow$  1; hlp1 { use this with one help line }
define help2  $\equiv$  begin help_ptr  $\leftarrow$  2; hlp2 { use this with two help lines }
define help3  $\equiv$  begin help_ptr  $\leftarrow$  3; hlp3 { use this with three help lines }
define help4  $\equiv$  begin help_ptr  $\leftarrow$  4; hlp4 { use this with four help lines }
define help5  $\equiv$  begin help_ptr  $\leftarrow$  5; hlp5 { use this with five help lines }
define help6  $\equiv$  begin help_ptr  $\leftarrow$  6; hlp6 { use this with six help lines }

⟨Global variables 13⟩ +=
help_line: array [0 .. 5] of str_number; { helps for the next error }
help_ptr: 0 .. 6; { the number of help lines present }
use_err_help: boolean; { should the err_help list be shown? }

```

80. ⟨Set initial values of key variables 21⟩ +=
help_ptr \leftarrow 0; *use_err_help* \leftarrow *false*;

81. The *jump_out* procedure just cuts across all active procedure levels and goes to *end_of_TEX*. This is the only nontrivial **goto** statement in the whole program. It is used when there is no recovery from a particular error.

Some Pascal compilers do not implement non-local **goto** statements. In such cases the body of *jump_out* should simply be ‘*close_files_and_terminate*;

```

⟨Error handling procedures 78⟩ +=
procedure jump_out;
  begin goto end_of_TEX;
end;

```

82. Here now is the general *error* routine.

```

⟨Error handling procedures 78⟩ +=
procedure error; { completes the job of error reporting }
  label continue, exit;
  var c: ASCII_code; { what the user types }
      s1, s2, s3, s4: integer; { used to save global variables when deleting tokens }
  begin if history < error_message_issued then history  $\leftarrow$  error_message_issued;
    print_char("."); show_context;
    if interaction = error_stop_mode then ⟨Get user's advice and return 83⟩;
    incr(error_count);
    if error_count = 100 then
      begin print_nl("(That_makes_100_errors;_please_try_again.)"); history  $\leftarrow$  fatal_error_stop;
        jump_out;
      end;
    ⟨Put help message on the transcript file 90⟩;
  exit: end;

```

83. \langle Get user's advice and **return** 83 $\rangle \equiv$
begin *continue*: **if** *interaction* \neq *error_stop_mode* **then** **return**;
clear_for_error_prompt; *prompt_input*("?");
if *last* = *first* **then** **return**;
c \leftarrow *buffer*[*first*];
if *c* \geq "a" **then** *c* \leftarrow *c* + "A" - "a"; { convert to uppercase }
 \langle Interpret code *c* and **return** if done 84 \rangle ;
end

This code is used in section 82.

84. It is desirable to provide an 'E' option here that gives the user an easy way to return from T_EX to the system editor, with the offending line ready to be edited. But such an extension requires some system wizardry, so the present implementation simply types out the name of the file that should be edited and the relevant line number.

There is a secret 'D' option available when the debugging routines haven't been commented out.

\langle Interpret code *c* and **return** if done 84 $\rangle \equiv$
case *c* **of**
 "0", "1", "2", "3", "4", "5", "6", "7", "8", "9": **if** *deletions_allowed* **then**
 \langle Delete *c* - "0" tokens and **goto** *continue* 88 \rangle ;
debug "D": **begin** *debug_help*; **goto** *continue*; **end**; **gubed**
 "E": **if** *base_ptr* > 0 **then**
if *input_stack*[*base_ptr*].*name_field* \geq 256 **then**
begin *print_nl*("You want to edit file"); *slow_print*(*input_stack*[*base_ptr*].*name_field*);
print(" at line"); *print_int*(*line*); *interaction* \leftarrow *scroll_mode*; *jump_out*;
end;
 "H": \langle Print the help information and **goto** *continue* 89 \rangle ;
 "I": \langle Introduce new material from the terminal and **return** 87 \rangle ;
 "Q", "R", "S": \langle Change the interaction level and **return** 86 \rangle ;
 "X": **begin** *interaction* \leftarrow *scroll_mode*; *jump_out*;
end;
othercases *do_nothing*
endcases;
 \langle Print the menu of available options 85 \rangle

This code is used in section 83.

85. \langle Print the menu of available options 85 $\rangle \equiv$
begin *print*("Type <return> to proceed, S to scroll future error messages,");
print_nl("R to run without stopping, Q to run quietly,");
print_nl("I to insert something,");
if *base_ptr* > 0 **then**
if *input_stack*[*base_ptr*].*name_field* \geq 256 **then** *print*("E to edit your file,");
if *deletions_allowed* **then**
print_nl("1 or ... or 9 to ignore the next 1 to 9 tokens of input,");
print_nl("H for help, X to quit.");
end

This code is used in section 84.

86. Here the author of TeX apologizes for making use of the numerical relation between "Q", "R", "S", and the desired interaction settings *batch_mode*, *nonstop_mode*, *scroll_mode*.

```
<Change the interaction level and return 86> ≡
  begin error_count ← 0; interaction ← batch_mode + c - "Q"; print("OK,␣entering␣");
  case c of
    "Q": begin print_esc("batchmode"); decr(selector);
      end;
    "R": print_esc("nonstopmode");
    "S": print_esc("scrollmode");
  end; {there are no other cases}
  print("..."); print_ln; update_terminal; return;
end
```

This code is used in section 84.

87. When the following code is executed, *buffer*[(*first* + 1) .. (*last* - 1)] may contain the material inserted by the user; otherwise another prompt will be given. In order to understand this part of the program fully, you need to be familiar with TeX's input stacks.

```
<Introduce new material from the terminal and return 87> ≡
  begin begin_file_reading; {enter a new syntactic level for terminal input}
    {now state = mid_line, so an initial blank space will count as a blank}
  if last > first + 1 then
    begin loc ← first + 1; buffer[first] ← "␣";
    end
  else begin prompt_input("insert>"); loc ← first;
    end;
  first ← last; cur_input.limit_field ← last - 1; {no end_line_char ends this line}
  return;
end
```

This code is used in section 84.

88. We allow deletion of up to 99 tokens at a time.

```
<Delete c - "0" tokens and goto continue 88> ≡
  begin s1 ← cur_tok; s2 ← cur_cmd; s3 ← cur_chr; s4 ← align_state; align_state ← 1000000;
  OK_to_interrupt ← false;
  if (last > first + 1) ∧ (buffer[first + 1] ≥ "0") ∧ (buffer[first + 1] ≤ "9") then
    c ← c * 10 + buffer[first + 1] - "0" * 11
  else c ← c - "0";
  while c > 0 do
    begin get_token; {one-level recursive call of error is possible}
    decr(c);
    end;
  cur_tok ← s1; cur_cmd ← s2; cur_chr ← s3; align_state ← s4; OK_to_interrupt ← true;
  help2("I␣have␣just␣deleted␣some␣text,␣as␣you␣asked.")
  ("You␣can␣now␣delete␣more,␣or␣insert,␣or␣whatever."); show_context; goto continue;
end
```

This code is used in section 84.

```

89.  ⟨Print the help information and goto continue 89⟩ ≡
    begin if use_err_help then
      begin give_err_help; use_err_help ← false;
      end
    else begin if help_ptr = 0 then help2("Sorry, I don't know how to help in this situation.")
      ("Maybe you should try asking a human?");
      repeat decr(help_ptr); print(help_line[help_ptr]); print_ln;
      until help_ptr = 0;
      end;
    help4("Sorry, I already gave what help I could...")
    ("Maybe you should try asking a human?")
    ("An error might have occurred before I noticed any problems.")
    ("`If all else fails, read the instructions.`");
    goto continue;
  end

```

This code is used in section 84.

```

90.  ⟨Put help message on the transcript file 90⟩ ≡
    if interaction > batch_mode then decr(selector); { avoid terminal output }
    if use_err_help then
      begin print_ln; give_err_help;
      end
    else while help_ptr > 0 do
      begin decr(help_ptr); print_nl(help_line[help_ptr]);
      end;
    print_ln;
    if interaction > batch_mode then incr(selector); { re-enable terminal output }
    print_ln

```

This code is used in section 82.

91. A dozen or so error messages end with a parenthesized integer, so we save a teeny bit of program space by declaring the following procedure:

```

procedure int_error(n : integer);
  begin print("("); print_int(n); print_char(")"); error;
  end;

```

92. In anomalous cases, the print selector might be in an unknown state; the following subroutine is called to fix things just enough to keep running a bit longer.

```

procedure normalize_selector;
  begin if log_opened then selector ← term_and_log
  else selector ← term_only;
  if job_name = 0 then open_log_file;
  if interaction = batch_mode then decr(selector);
  end;

```

93. The following procedure prints TEX's last words before dying.

```

define succumb ≡
  begin if interaction = error_stop_mode then interaction ← scroll_mode;
    { no more interaction }
  if log_opened then error;
  debug if interaction > batch_mode then debug_help;
  gubed
  history ← fatal_error_stop; jump_out; { irrecoverable error }
  end

⟨Error handling procedures 78⟩ +≡
procedure fatal_error(s : str_number); { prints s, and that's it }
  begin normalize_selector;
  print_err("Emergency_stop"); help1(s); succumb;
  end;

```

94. Here is the most dreaded error message.

```

⟨Error handling procedures 78⟩ +≡
procedure overflow(s : str_number; n : integer); { stop due to finiteness }
  begin normalize_selector; print_err("TeX_capacity_exceeded_sorry_["); print(s); print_char("=");
  print_int(n); print_char("]"); help2("If_you_really_absolutely_need_more_capacity,"
  ("you_can_ask_a_wizard_to_enlarge_me."); succumb;
  end;

```

95. The program might sometime run completely amok, at which point there is no choice but to stop. If no previous error has been detected, that's bad news; a message is printed that is really intended for the TEX maintenance person instead of the user (unless the user has been particularly diabolical). The index entries for 'this can't happen' may help to pinpoint the problem.

```

⟨Error handling procedures 78⟩ +≡
procedure confusion(s : str_number); { consistency check violated; s tells where }
  begin normalize_selector;
  if history < error_message_issued then
    begin print_err("This_can't_happen_("); print(s); print_char(")");
    help1("I'm_broken._Please_show_this_to_someone_who_can_fix_can_fix");
    end
  else begin print_err("I_can't_go_on_meeting_you_like_this");
    help2("One_of_your_faux_pas_seems_to_have_wounded_me_deeply...")
    ("in_fact,_I'm_barely_conscious._Please_fix_it_and_try_again.");
    end;
  succumb;
  end;

```

96. Users occasionally want to interrupt TEX while it's running. If the Pascal runtime system allows this, one can implement a routine that sets the global variable *interrupt* to some nonzero value when such an interrupt is signalled. Otherwise there is probably at least a way to make *interrupt* nonzero using the Pascal debugger.

```

define check_interrupt ≡
  begin if interrupt ≠ 0 then pause_for_instructions;
  end

⟨Global variables 13⟩ +≡
interrupt: integer; { should TEX pause for instructions? }
OK_to_interrupt: boolean; { should interrupts be observed? }

```

97. \langle Set initial values of key variables 21 $\rangle + \equiv$
 $interrupt \leftarrow 0; OK_to_interrupt \leftarrow true;$

98. When an interrupt has been detected, the program goes into its highest interaction level and lets the user have nearly the full flexibility of the *error* routine. TeX checks for interrupts only at times when it is safe to do this.

```
procedure pause_for_instructions;
begin if OK_to_interrupt then
  begin interaction  $\leftarrow$  error_stop_mode;
  if (selector = log_only)  $\vee$  (selector = no_print) then incr(selector);
  print_err("Interruption"); help3("You_rang?")
  ("Try_to_insert_an_instruction_for_me_(e.g.,_`I\showlists`),")
  ("unless_you_just_want_to_quit_by_typing_`X`."); deletions_allowed  $\leftarrow$  false; error;
  deletions_allowed  $\leftarrow$  true; interrupt  $\leftarrow$  0;
  end;
end;
```

99. Arithmetic with scaled dimensions. The principal computations performed by TeX are done entirely in terms of integers less than 2^{31} in magnitude; and divisions are done only when both dividend and divisor are nonnegative. Thus, the arithmetic specified in this program can be carried out in exactly the same way on a wide variety of computers, including some small ones. Why? Because the arithmetic calculations need to be spelled out precisely in order to guarantee that TeX will produce identical output on different machines. If some quantities were rounded differently in different implementations, we would find that line breaks and even page breaks might occur in different places. Hence the arithmetic of TeX has been designed with care, and systems that claim to be implementations of TeX82 should follow precisely the calculations as they appear in the present program.

(Actually there are three places where TeX uses **div** with a possibly negative numerator. These are harmless; see **div** in the index. Also if the user sets the **\time** or the **\year** to a negative value, some diagnostic information will involve negative-numerator division. The same remarks apply for **mod** as well as for **div**.)

100. Here is a routine that calculates half of an integer, using an unambiguous convention with respect to signed odd numbers.

```
function half(x : integer): integer;
  begin if odd(x) then half  $\leftarrow$  (x + 1) div 2
  else half  $\leftarrow$  x div 2;
end;
```

101. Fixed-point arithmetic is done on *scaled integers* that are multiples of 2^{-16} . In other words, a binary point is assumed to be sixteen bit positions from the right end of a binary computer word.

```
define unity  $\equiv$  '200000 {  $2^{16}$ , represents 1.00000 }
define two  $\equiv$  '400000 {  $2^{17}$ , represents 2.00000 }

⟨Types in the outer block 18⟩ +=
  scaled = integer; { this type is used for scaled integers }
  nonnegative_integer = 0 .. '177777777777; {  $0 \leq x < 2^{31}$  }
  small_number = 0 .. 63; { this type is self-explanatory }
```

102. The following function is used to create a scaled integer from a given decimal fraction $(.d_0d_1 \dots d_{k-1})$, where $0 \leq k \leq 17$. The digit d_i is given in *dig*[*i*], and the calculation produces a correctly rounded result.

```
function round_decimals(k : small_number): scaled; { converts a decimal fraction }
  var a: integer; { the accumulator }
  begin a  $\leftarrow$  0;
  while k > 0 do
    begin decr(k); a  $\leftarrow$  (a + dig[k] * two) div 10;
    end;
  round_decimals  $\leftarrow$  (a + 1) div 2;
end;
```

103. Conversely, here is a procedure analogous to *print_int*. If the output of this procedure is subsequently read by T_EX and converted by the *round_decimals* routine above, it turns out that the original value will be reproduced exactly; the “simplest” such decimal number is output, but there is always at least one digit following the decimal point.

The invariant relation in the **repeat** loop is that a sequence of decimal digits yet to be printed will yield the original number if and only if they form a fraction f in the range $s - \delta \leq 10 \cdot 2^{16} f < s$. We can stop if and only if $f = 0$ satisfies this condition; the loop will terminate before s can possibly become zero.

```
procedure print_scaled( $s$  : scaled); { prints scaled real, rounded to five digits }
  var  $\delta$ : scaled; { amount of allowable inaccuracy }
  begin if  $s < 0$  then
    begin print_char("−"); negate( $s$ ); { print the sign, if negative }
    end;
    print_int( $s \text{ div } \text{unity}$ ); { print the integer part }
    print_char(".");  $s \leftarrow 10 * (s \text{ mod } \text{unity}) + 5$ ;  $\delta \leftarrow 10$ ;
    repeat if  $\delta > \text{unity}$  then  $s \leftarrow s + '100000 - 50000$ ; { round the last digit }
      print_char("0" + ( $s \text{ div } \text{unity}$ ));  $s \leftarrow 10 * (s \text{ mod } \text{unity})$ ;  $\delta \leftarrow \delta * 10$ ;
    until  $s \leq \delta$ ;
  end;
```

104. Physical sizes that a T_EX user specifies for portions of documents are represented internally as scaled points. Thus, if we define an ‘sp’ (scaled point) as a unit equal to 2^{-16} printer’s points, every dimension inside of T_EX is an integer number of sp. There are exactly 4,736,286.72 sp per inch. Users are not allowed to specify dimensions larger than $2^{30} - 1$ sp, which is a distance of about 18.892 feet (5.7583 meters); two such quantities can be added without overflow on a 32-bit computer.

The present implementation of T_EX does not check for overflow when dimensions are added or subtracted. This could be done by inserting a few dozen tests of the form ‘**if** $x \geq '10000000000$ **then** *report_overflow*’, but the chance of overflow is so remote that such tests do not seem worthwhile.

T_EX needs to do only a few arithmetic operations on scaled quantities, other than addition and subtraction, and the following subroutines do most of the work. A single computation might use several subroutine calls, and it is desirable to avoid producing multiple error messages in case of arithmetic overflow; so the routines set the global variable *arith_error* to *true* instead of reporting errors directly to the user. Another global variable, *remainder*, holds the remainder after a division.

⟨Global variables 13⟩ +≡

```
arith_error: boolean; { has arithmetic overflow occurred recently? }
remainder: scaled; { amount subtracted to get an exact division }
```

105. The first arithmetical subroutine we need computes $nx + y$, where x and y are *scaled* and n is an integer. We will also use it to multiply integers.

```
define nx_plus_y( $\#$ )  $\equiv$  mult_and_add( $\#$ , '77777777777777777777')
define mult_integers( $\#$ )  $\equiv$  mult_and_add( $\#$ , 0, '77777777777777777777')
function mult_and_add( $n$  : integer;  $x, y, \text{max\_answer}$  : scaled): scaled;
  begin if  $n < 0$  then
    begin negate( $x$ ); negate( $n$ );
    end;
  if  $n = 0$  then mult_and_add  $\leftarrow y$ 
  else if ( $(x \leq (\text{max\_answer} - y) \text{ div } n) \wedge (-x \leq (\text{max\_answer} + y) \text{ div } n)$ ) then mult_and_add  $\leftarrow n * x + y$ 
    else begin arith_error  $\leftarrow \text{true}$ ; mult_and_add  $\leftarrow 0$ ;
    end;
  end;
```


106. We also need to divide scaled dimensions by integers.

```
function x_over_n(x : scaled; n : integer): scaled;
  var negative: boolean; { should remainder be negated? }
  begin negative  $\leftarrow$  false;
  if n = 0 then
    begin arith_error  $\leftarrow$  true; x_over_n  $\leftarrow$  0; remainder  $\leftarrow$  x;
    end
  else begin if n < 0 then
    begin negate(x); negate(n); negative  $\leftarrow$  true;
    end;
    if x  $\geq$  0 then
      begin x_over_n  $\leftarrow$  x div n; remainder  $\leftarrow$  x mod n;
      end
    else begin x_over_n  $\leftarrow$   $-((-x) \text{ div } n)$ ; remainder  $\leftarrow$   $-((-x) \text{ mod } n)$ ;
    end;
    end;
  if negative then negate(remainder);
end;
```

107. Then comes the multiplication of a scaled number by a fraction n/d , where n and d are nonnegative integers $\leq 2^{16}$ and d is positive. It would be too dangerous to multiply by n and then divide by d , in separate operations, since overflow might well occur; and it would be too inaccurate to divide by d and then multiply by n . Hence this subroutine simulates 1.5-precision arithmetic.

```
function xn_over_d(x : scaled; n, d : integer): scaled;
  var positive: boolean; { was x  $\geq$  0? }
  t, u, v: nonnegative_integer; { intermediate quantities }
  begin if x  $\geq$  0 then positive  $\leftarrow$  true
  else begin negate(x); positive  $\leftarrow$  false;
  end;
  t  $\leftarrow$  (x mod '100000) * n; u  $\leftarrow$  (x div '100000) * n + (t div '100000);
  v  $\leftarrow$  (u mod d) * '100000 + (t mod '100000);
  if u div d  $\geq$  '100000 then arith_error  $\leftarrow$  true
  else u  $\leftarrow$  '100000 * (u div d) + (v div d);
  if positive then
    begin xn_over_d  $\leftarrow$  u; remainder  $\leftarrow$  v mod d;
    end
  else begin xn_over_d  $\leftarrow$   $-u$ ; remainder  $\leftarrow$   $-(v \text{ mod } d)$ ;
  end;
end;
```

108. The next subroutine is used to compute the “badness” of glue, when a total t is supposed to be made from amounts that sum to s . According to *The T_EXbook*, the badness of this situation is $100(t/s)^3$; however, badness is simply a heuristic, so we need not squeeze out the last drop of accuracy when computing it. All we really want is an approximation that has similar properties.

The actual method used to compute the badness is easier to read from the program than to describe in words. It produces an integer value that is a reasonably close approximation to $100(t/s)^3$, and all implementations of T_EX should use precisely this method. Any badness of 2^{13} or more is treated as infinitely bad, and represented by 10000.

It is not difficult to prove that

$$\text{badness}(t+1, s) \geq \text{badness}(t, s) \geq \text{badness}(t, s+1).$$

The badness function defined here is capable of computing at most 1095 distinct values, but that is plenty.

```

define inf_bad = 10000 { infinitely bad value }
function badness(t, s : scaled): halfword; { compute badness, given  $t \geq 0$  }
var r: integer; { approximation to  $\alpha t/s$ , where  $\alpha^3 \approx 100 \cdot 2^{18}$  }
begin if  $t = 0$  then badness  $\leftarrow 0$ 
else if  $s \leq 0$  then badness  $\leftarrow$  inf_bad
else begin if  $t \leq 7230584$  then  $r \leftarrow (t * 297) \text{ div } s$  {  $297^3 = 99.94 \times 2^{18}$  }
else if  $s \geq 1663497$  then  $r \leftarrow t \text{ div } (s \text{ div } 297)$ 
else  $r \leftarrow t$ ;
if  $r > 1290$  then badness  $\leftarrow$  inf_bad {  $1290^3 < 2^{31} < 1291^3$  }
else badness  $\leftarrow (r * r * r + '400000) \text{ div } '1000000$ ;
end; { that was  $r^3/2^{18}$ , rounded to the nearest integer }
end;

```

109. When T_EX “packages” a list into a box, it needs to calculate the proportionality ratio by which the glue inside the box should stretch or shrink. This calculation does not affect T_EX’s decision making, so the precise details of rounding, etc., in the glue calculation are not of critical importance for the consistency of results on different computers.

We shall use the type *glue_ratio* for such proportionality ratios. A glue ratio should take the same amount of memory as an *integer* (usually 32 bits) if it is to blend smoothly with T_EX’s other data structures. Thus *glue_ratio* should be equivalent to *short_real* in some implementations of Pascal. Alternatively, it is possible to deal with glue ratios using nothing but fixed-point arithmetic; see *TUGboat* **3**,1 (March 1982), 10–27. (But the routines cited there must be modified to allow negative glue ratios.)

```

define set_glue_ratio_zero(#)  $\equiv$  #  $\leftarrow$  0.0 { store the representation of zero ratio }
define set_glue_ratio_one(#)  $\equiv$  #  $\leftarrow$  1.0 { store the representation of unit ratio }
define float(#)  $\equiv$  # { convert from glue_ratio to type real }
define unfloat(#)  $\equiv$  # { convert from real to type glue_ratio }
define float_constant(#)  $\equiv$  #.0 { convert integer constant to real }

```

⟨Types in the outer block 18⟩ +=

```

glue_ratio = real; { one-word representation of a glue expansion factor }

```

110. Random numbers. This section is (almost) straight from METAPOST. I had to change the types (use *integer* instead of *fraction*), but that should not have any influence on the actual calculations (the original comments refer to quantities like *fraction_four* (2^{30}), and that is the same as the numeric representation of *maxdimen*).

I've copied the low-level variables and routines that are needed, but only those (e.g. *m_log*), not the accompanying ones like *m_exp*. Most of the following low-level numeric routines are only needed within the calculation of *norm_rand*. I've been forced to rename *make_fraction* to *make_frac* because TeX already has a routine by that name with a wholly different function (it creates a *fraction_noad* for math typesetting) – Taco.

And now let's complete our collection of numeric utility routines by considering random number generation. METAPOST generates pseudo-random numbers with the additive scheme recommended in Section 3.6 of *The Art of Computer Programming*; however, the results are random fractions between 0 and *fraction_one* – 1, inclusive.

There's an auxiliary array *randoms* that contains 55 pseudo-random fractions. Using the recurrence $x_n = (x_{n-55} - x_{n-31}) \bmod 2^{28}$, we generate batches of 55 new x_n 's at a time by calling *new_randoms*. The global variable *j_random* tells which element has most recently been consumed.

```

⟨Global variables 13⟩ +=
randoms: array [0 .. 54] of integer; { the last 55 random values generated }
j_random: 0 .. 54; { the number of unused randoms }
random_seed: scaled; { the default random seed }

```

111. A small bit of METAFONT is needed.

```

define fraction_half ≡ '1000000000 {  $2^{27}$ , represents 0.50000000 }
define fraction_one ≡ '2000000000 {  $2^{28}$ , represents 1.00000000 }
define fraction_four ≡ '10000000000 {  $2^{30}$ , represents 4.00000000 }
define el_gordo ≡ '177777777777 {  $2^{31} - 1$ , the largest value that METAPOST likes }
define halfp(#) ≡ (#) div 2
define double(#) ≡ # ← # + # { multiply a variable by two }

```

112. The *make_frac* routine produces the *fraction* equivalent of p/q , given integers p and q ; it computes the integer $f = \lfloor 2^{28}p/q + \frac{1}{2} \rfloor$, when p and q are positive. If p and q are both of the same scaled type t , the “type relation” *make_frac*(t, t) = *fraction* is valid; and it’s also possible to use the subroutine “backwards,” using the relation *make_frac*($t, fraction$) = t between scaled types.

If the result would have magnitude 2^{31} or more, *make_frac* sets *arith_error* \leftarrow *true*. Most of METAPOST’s internal computations have been designed to avoid this sort of error.

If this subroutine were programmed in assembly language on a typical machine, we could simply compute $(2^{28} * p) \text{ div } q$, since a double-precision product can often be input to a fixed-point division instruction. But when we are restricted to Pascal arithmetic it is necessary either to resort to multiple-precision maneuvering or to use a simple but slow iteration. The multiple-precision technique would be about three times faster than the code adopted here, but it would be comparatively long and tricky, involving about sixteen additional multiplications and divisions.

This operation is part of METAPOST’s “inner loop”; indeed, it will consume nearly 10% of the running time (exclusive of input and output) if the code below is left unchanged. A machine-dependent recoding will therefore make METAPOST run faster. The present implementation is highly portable, but slow; it avoids multiplication and division except in the initial stage. System wizards should be careful to replace it with a routine that is guaranteed to produce identical results in all cases.

As noted below, a few more routines should also be replaced by machine-dependent code, for efficiency. But when a procedure is not part of the “inner loop,” such changes aren’t advisable; simplicity and robustness are preferable to trickery, unless the cost is too high.

```
function make_frac( $p, q : integer$ ): integer;
  var  $f : integer$ ; { the fraction bits, with a leading 1 bit }
   $n : integer$ ; { the integer part of  $|p/q|$  }
   $negative : boolean$ ; { should the result be negated? }
   $be\_careful : integer$ ; { disables certain compiler optimizations }
  begin if  $p \geq 0$  then  $negative \leftarrow false$ 
  else begin  $negate(p)$ ;  $negative \leftarrow true$ ;
  end;
  if  $q \leq 0$  then
    begin debug if  $q = 0$  then  $confusion("/")$ ; gubed
     $negate(q)$ ;  $negative \leftarrow \neg negative$ ;
    end;
   $n \leftarrow p \text{ div } q$ ;  $p \leftarrow p \bmod q$ ;
  if  $n \geq 8$  then
    begin  $arith\_error \leftarrow true$ ;
    if  $negative$  then  $make\_frac \leftarrow -el\_gordo$  else  $make\_frac \leftarrow el\_gordo$ ;
    end
  else begin  $n \leftarrow (n - 1) * fraction\_one$ ; { Compute  $f = \lfloor 2^{28}(1 + p/q) + \frac{1}{2} \rfloor$  113 };
    if  $negative$  then  $make\_frac \leftarrow -(f + n)$  else  $make\_frac \leftarrow f + n$ ;
    end;
  end;
```

113. The **repeat** loop here preserves the following invariant relations between f , p , and q : (i) $0 \leq p < q$; (ii) $f q + p = 2^k(q + p_0)$, where k is an integer and p_0 is the original value of p .

Notice that the computation specifies $(p - q) + p$ instead of $(p + p) - q$, because the latter could overflow. Let us hope that optimizing compilers do not miss this point; a special variable *be_careful* is used to emphasize the necessary order of computation. Optimizing compilers should keep *be_careful* in a register, not store it in memory.

```

⟨ Compute  $f = \lfloor 2^{28}(1 + p/q) + \frac{1}{2} \rfloor$  113 ⟩ ≡
   $f \leftarrow 1$ ;
  repeat  $be\_careful \leftarrow p - q$ ;  $p \leftarrow be\_careful + p$ ;
    if  $p \geq 0$  then  $f \leftarrow f + f + 1$ 
    else begin  $double(f)$ ;  $p \leftarrow p + q$ ;
    end;
  until  $f \geq fraction\_one$ ;
   $be\_careful \leftarrow p - q$ ;
  if  $be\_careful + p \geq 0$  then  $incr(f)$ 

```

This code is used in section 112.

114.

```

function  $take\_frac(q : integer; f : integer) : integer$ ;
  var  $p : integer$ ; { the fraction so far }
   $negative : boolean$ ; { should the result be negated? }
   $n : integer$ ; { additional multiple of  $q$  }
   $be\_careful : integer$ ; { disables certain compiler optimizations }
  begin ⟨ Reduce to the case that  $f \geq 0$  and  $q > 0$  115 ⟩;
  if  $f < fraction\_one$  then  $n \leftarrow 0$ 
  else begin  $n \leftarrow f \text{ div } fraction\_one$ ;  $f \leftarrow f \text{ mod } fraction\_one$ ;
    if  $q \leq el\_gordo \text{ div } n$  then  $n \leftarrow n * q$ 
    else begin  $arith\_error \leftarrow true$ ;  $n \leftarrow el\_gordo$ ;
    end;
  end;
   $f \leftarrow f + fraction\_one$ ; ⟨ Compute  $p = \lfloor qf/2^{28} + \frac{1}{2} \rfloor - q$  116 ⟩;
   $be\_careful \leftarrow n - el\_gordo$ ;
  if  $be\_careful + p > 0$  then
    begin  $arith\_error \leftarrow true$ ;  $n \leftarrow el\_gordo - p$ ;
    end;
  if  $negative$  then  $take\_frac \leftarrow -(n + p)$ 
  else  $take\_frac \leftarrow n + p$ ;
  end;

```

115. ⟨ Reduce to the case that $f \geq 0$ and $q > 0$ 115 ⟩ ≡

```

if  $f \geq 0$  then  $negative \leftarrow false$ 
else begin  $negate(f)$ ;  $negative \leftarrow true$ ;
  end;
if  $q < 0$  then
  begin  $negate(q)$ ;  $negative \leftarrow \neg negative$ ;
  end;

```

This code is used in section 114.

116. The invariant relations in this case are (i) $\lfloor (qf + p)/2^k \rfloor = \lfloor qf_0/2^{28} + \frac{1}{2} \rfloor$, where k is an integer and f_0 is the original value of f ; (ii) $2^k \leq f < 2^{k+1}$.

```

⟨ Compute  $p = \lfloor qf/2^{28} + \frac{1}{2} \rfloor - q$  116 ⟩ ≡
   $p \leftarrow \text{fraction\_half}$ ; { that's  $2^{27}$ ; the invariants hold now with  $k = 28$  }
  if  $q < \text{fraction\_four}$  then
    repeat if odd( $f$ ) then  $p \leftarrow \text{halfp}(p + q)$  else  $p \leftarrow \text{halfp}(p)$ ;
       $f \leftarrow \text{halfp}(f)$ ;
    until  $f = 1$ 
  else repeat if odd( $f$ ) then  $p \leftarrow p + \text{halfp}(q - p)$  else  $p \leftarrow \text{halfp}(p)$ ;
     $f \leftarrow \text{halfp}(f)$ ;
  until  $f = 1$ 

```

This code is used in section 114.

117. The subroutines for logarithm and exponential involve two tables. The first is simple: $\text{two_to_the}[k]$ equals 2^k . The second involves a bit more calculation, which the author claims to have done correctly: $\text{spec_log}[k]$ is 2^{27} times $\ln(1/(1 - 2^{-k})) = 2^{-k} + \frac{1}{2}2^{-2k} + \frac{1}{3}2^{-3k} + \dots$, rounded to the nearest integer.

```

⟨ Global variables 13 ⟩ +≡
two_to_the: array [0 .. 30] of integer; { powers of two }
spec_log: array [1 .. 28] of integer; { special logarithms }

```

118. ⟨ Set initial values of key variables 21 ⟩ +≡

```

two_to_the[0] ← 1;
for  $k \leftarrow 1$  to 30 do two_to_the[k] ← 2 * two_to_the[k - 1];
spec_log[1] ← 93032640; spec_log[2] ← 38612034; spec_log[3] ← 17922280; spec_log[4] ← 8662214;
spec_log[5] ← 4261238; spec_log[6] ← 2113709; spec_log[7] ← 1052693; spec_log[8] ← 525315;
spec_log[9] ← 262400; spec_log[10] ← 131136; spec_log[11] ← 65552; spec_log[12] ← 32772;
spec_log[13] ← 16385;
for  $k \leftarrow 14$  to 27 do spec_log[k] ← two_to_the[27 - k];
spec_log[28] ← 1;

```

119.

```

function m_log( $x$  : integer): integer;
  var  $y, z$ : integer; { auxiliary registers }
   $k$ : integer; { iteration counter }
  begin if  $x \leq 0$  then ⟨ Handle non-positive logarithm 121 ⟩
  else begin  $y \leftarrow 1302456956 + 4 - 100$ ; {  $14 \times 2^{27} \ln 2 \approx 1302456956.421063$  }
     $z \leftarrow 27595 + 6553600$ ; { and  $2^{16} \times .421063 \approx 27595$  }
    while  $x < \text{fraction\_four}$  do
      begin double( $x$ );  $y \leftarrow y - 93032639$ ;  $z \leftarrow z - 48782$ ;
      end; {  $2^{27} \ln 2 \approx 93032639.74436163$  and  $2^{16} \times .74436163 \approx 48782$  }
     $y \leftarrow y + (z \text{ div } \text{unity})$ ;  $k \leftarrow 2$ ;
    while  $x > \text{fraction\_four} + 4$  do
      ⟨ Increase  $k$  until  $x$  can be multiplied by a factor of  $2^{-k}$ , and adjust  $y$  accordingly 120 ⟩;
       $m\_log \leftarrow y \text{ div } 8$ ;
    end;
  end;
end;

```

120. \langle Increase k until x can be multiplied by a factor of 2^{-k} , and adjust y accordingly 120 $\rangle \equiv$

```

begin  $z \leftarrow ((x - 1) \text{ div } \textit{two\_to\_the}[k]) + 1; \{ z = \lceil x/2^k \rceil \}$ 
while  $x < \textit{fraction\_four} + z$  do
  begin  $z \leftarrow \textit{halfp}(z + 1); k \leftarrow k + 1;$ 
  end;
 $y \leftarrow y + \textit{spec\_log}[k]; x \leftarrow x - z;$ 
end

```

This code is used in section 119.

121. \langle Handle non-positive logarithm 121 $\rangle \equiv$

```

begin  $\textit{print\_err}(\text{"Logarithm\_of\_"}); \textit{print\_scaled}(x); \textit{print}(\text{"\_has\_been\_replaced\_by\_0"});$ 
 $\textit{help2}(\text{"Since\_I\_don't\_take\_logs\_of\_non-positive\_numbers,"})$ 
 $(\text{"I'm\_zeroing\_this\_one.\_Proceed,\_with\_fingers\_crossed."}); \textit{error}; m\_log \leftarrow 0;$ 
end

```

This code is used in section 119.

122. The following somewhat different subroutine tests rigorously if ab is greater than, equal to, or less than cd , given integers (a, b, c, d) . In most cases a quick decision is reached. The result is +1, 0, or -1 in the three respective cases.

```

define  $\textit{return\_sign}(\#) \equiv$ 
  begin  $ab\_vs\_cd \leftarrow \#; \textit{return};$ 
  end

function  $ab\_vs\_cd(a, b, c, d : \textit{integer}) : \textit{integer};$ 
  label  $\textit{exit};$ 
  var  $q, r : \textit{integer}; \{ \text{temporary registers} \}$ 
  begin  $\langle$  Reduce to the case that  $a, c \geq 0, b, d > 0$  123  $\rangle;$ 
  loop begin  $q \leftarrow a \text{ div } d; r \leftarrow c \text{ div } b;$ 
    if  $q \neq r$  then
      if  $q > r$  then  $\textit{return\_sign}(1)$  else  $\textit{return\_sign}(-1);$ 
       $q \leftarrow a \text{ mod } d; r \leftarrow c \text{ mod } b;$ 
    if  $r = 0$  then
      if  $q = 0$  then  $\textit{return\_sign}(0)$  else  $\textit{return\_sign}(1);$ 
    if  $q = 0$  then  $\textit{return\_sign}(-1);$ 
     $a \leftarrow b; b \leftarrow q; c \leftarrow d; d \leftarrow r;$ 
  end;  $\{ \text{now } a > d > 0 \text{ and } c > b > 0 \}$ 
 $\textit{exit: end};$ 

```

123. $\langle \text{Reduce to the case that } a, c \geq 0, b, d > 0 \text{ 123} \rangle \equiv$

```

if  $a < 0$  then
  begin  $negate(a)$ ;  $negate(b)$ ;
  end;
if  $c < 0$  then
  begin  $negate(c)$ ;  $negate(d)$ ;
  end;
if  $d \leq 0$  then
  begin if  $b \geq 0$  then
    if  $((a = 0) \vee (b = 0)) \wedge ((c = 0) \vee (d = 0))$  then  $return\_sign(0)$ 
    else  $return\_sign(1)$ ;
  if  $d = 0$  then
    if  $a = 0$  then  $return\_sign(0)$  else  $return\_sign(-1)$ ;
     $q \leftarrow a$ ;  $a \leftarrow c$ ;  $c \leftarrow q$ ;  $q \leftarrow -b$ ;  $b \leftarrow -d$ ;  $d \leftarrow q$ ;
  end
else if  $b \leq 0$  then
  begin if  $b < 0$  then
    if  $a > 0$  then  $return\_sign(-1)$ ;
    if  $c = 0$  then  $return\_sign(0)$ 
    else  $return\_sign(-1)$ ;
  end

```

This code is used in section 122.

124. To consume a random integer, the program below will say ‘*next_random*’ and then it will fetch *randoms*[*j_random*].

```

define  $next\_random \equiv$ 
  if  $j\_random = 0$  then  $new\_randoms$ 
  else  $decr(j\_random)$ 
procedure  $new\_randoms$ ;
  var  $k$ :  $0 \dots 54$ ; { index into  $randoms$  }
   $x$ :  $integer$ ; { accumulator }
  begin for  $k \leftarrow 0$  to 23 do
    begin  $x \leftarrow randoms[k] - randoms[k + 31]$ ;
    if  $x < 0$  then  $x \leftarrow x + fraction\_one$ ;
     $randoms[k] \leftarrow x$ ;
  end;
  for  $k \leftarrow 24$  to 54 do
    begin  $x \leftarrow randoms[k] - randoms[k - 24]$ ;
    if  $x < 0$  then  $x \leftarrow x + fraction\_one$ ;
     $randoms[k] \leftarrow x$ ;
  end;
   $j\_random \leftarrow 54$ ;
end;

```


125. To initialize the *randoms* table, we call the following routine.

```
procedure init_randoms(seed : integer);
  var j, jj, k: integer; { more or less random integers }
  i: 0 .. 54; { index into randoms }
  begin j  $\leftarrow$  abs(seed);
  while j  $\geq$  fraction_one do j  $\leftarrow$  halfp(j);
  k  $\leftarrow$  1;
  for i  $\leftarrow$  0 to 54 do
    begin jj  $\leftarrow$  k; k  $\leftarrow$  j - k; j  $\leftarrow$  jj;
    if k < 0 then k  $\leftarrow$  k + fraction_one;
    randoms[(i * 21) mod 55]  $\leftarrow$  j;
    end;
  new_randoms; new_randoms; new_randoms; { “warm up” the array }
end;
```

126. To produce a uniform random number in the range $0 \leq u < x$ or $0 \geq u > x$ or $0 = u = x$, given a *scaled* value *x*, we proceed as shown here.

Note that the call of *take_frac* will produce the values 0 and *x* with about half the probability that it will produce any other particular values between 0 and *x*, because it rounds its answers.

```
function unif_rand(x : integer): integer;
  var y: integer; { trial value }
  begin next_random; y  $\leftarrow$  take_frac(abs(x), randoms[j_random]);
  if y = abs(x) then unif_rand  $\leftarrow$  0
  else if x > 0 then unif_rand  $\leftarrow$  y
    else unif_rand  $\leftarrow$  -y;
  end;
```

127. Finally, a normal deviate with mean zero and unit standard deviation can readily be obtained with the ratio method (Algorithm 3.4.1R in *The Art of Computer Programming*).

```
function norm_rand: integer;
  var x, u, l: integer; { what the book would call  $2^{16}X$ ,  $2^{28}U$ , and  $-2^{24} \ln U$  }
  begin repeat repeat next_random; x  $\leftarrow$  take_frac(112429, randoms[j_random] - fraction_half);
    {  $2^{16} \sqrt{8/e} \approx 112428.82793$  }
    next_random; u  $\leftarrow$  randoms[j_random];
    until abs(x) < u;
    x  $\leftarrow$  make_frac(x, u); l  $\leftarrow$  139548960 - m_log(u); {  $2^{24} \cdot 12 \ln 2 \approx 139548959.6165$  }
  until ab_vs_cd(1024, l, x, x)  $\geq$  0;
  norm_rand  $\leftarrow$  x;
end;
```

128. Packed data. In order to make efficient use of storage space, T_EX bases its major data structures on a *memory_word*, which contains either a (signed) integer, possibly scaled, or a (signed) *glue_ratio*, or a small number of fields that are one half or one quarter of the size used for storing integers.

If x is a variable of type *memory_word*, it contains up to four fields that can be referred to as follows:

$x.int$	(an <i>integer</i>)
$x.sc$	(a <i>scaled</i> integer)
$x.gr$	(a <i>glue_ratio</i>)
$x.hh.lh, x.hh.rh$	(two halfword fields)
$x.hh.b0, x.hh.b1, x.hh.rh$	(two quarterword fields, one halfword field)
$x.qqqq.b0, x.qqqq.b1, x.qqqq.b2, x.qqqq.b3$	(four quarterword fields)

This is somewhat cumbersome to write, and not very readable either, but macros will be used to make the notation shorter and more transparent. The Pascal code below gives a formal definition of *memory_word* and its subsidiary types, using packed variant records. T_EX makes no assumptions about the relative positions of the fields within a word.

Since we are assuming 32-bit integers, a halfword must contain at least 16 bits, and a quarterword must contain at least 8 bits. But it doesn't hurt to have more bits; for example, with enough 36-bit words you might be able to have *mem_max* as large as 262142, which is eight times as much memory as anybody had during the first four years of T_EX's existence.

N.B.: Valuable memory space will be dreadfully wasted unless T_EX is compiled by a Pascal that packs all of the *memory_word* variants into the space of a single integer. This means, for example, that *glue_ratio* words should be *short_real* instead of *real* on some computers. Some Pascal compilers will pack an integer whose subrange is '0 .. 255' into an eight-bit field, but others insist on allocating space for an additional sign bit; on such systems you can get 256 values into a quarterword only if the subrange is '-128 .. 127'.

The present implementation tries to accommodate as many variations as possible, so it makes few assumptions. If integers having the subrange '*min_quarterword* .. *max_quarterword*' can be packed into a quarterword, and if integers having the subrange '*min_halfword* .. *max_halfword*' can be packed into a halfword, everything should work satisfactorily.

It is usually most efficient to have *min_quarterword* = *min_halfword* = 0, so one should try to achieve this unless it causes a severe problem. The values defined here are recommended for most 32-bit computers.

```

define min_quarterword = 0 {smallest allowable value in a quarterword}
define max_quarterword = 255 {largest allowable value in a quarterword}
define min_halfword ≡ 0 {smallest allowable value in a halfword}
define max_halfword ≡ 65535 {largest allowable value in a halfword}

```

129. Here are the inequalities that the quarterword and halfword values must satisfy (or rather, the inequalities that they mustn't satisfy):

<Check the "constant" values for consistency 14> +≡

```

init if (mem_min ≠ mem_bot) ∨ (mem_max ≠ mem_top) then bad ← 10;
tini
if (mem_min > mem_bot) ∨ (mem_max < mem_top) then bad ← 10;
if (min_quarterword > 0) ∨ (max_quarterword < 127) then bad ← 11;
if (min_halfword > 0) ∨ (max_halfword < 32767) then bad ← 12;
if (min_quarterword < min_halfword) ∨ (max_quarterword > max_halfword) then bad ← 13;
if (mem_min < min_halfword) ∨ (mem_max ≥ max_halfword) ∨
    (mem_bot - mem_min > max_halfword + 1) then bad ← 14;
if (font_base < min_quarterword) ∨ (font_max > max_quarterword) then bad ← 15;
if font_max > font_base + 256 then bad ← 16;
if (save_size > max_halfword) ∨ (max_strings > max_halfword) then bad ← 17;
if buf_size > max_halfword then bad ← 18;
if max_quarterword - min_quarterword < 255 then bad ← 19;

```

130. The operation of adding or subtracting *min_quarterword* occurs quite frequently in TeX, so it is convenient to abbreviate this operation by using the macros *qi* and *qo* for input and output to and from quarterword format.

The inner loop of TeX will run faster with respect to compilers that don't optimize expressions like ' $x + 0$ ' and ' $x - 0$ ', if these macros are simplified in the obvious way when *min_quarterword* = 0.

```
define qi(#) ≡ # + min_quarterword { to put an eight_bits item into a quarterword }
define qo(#) ≡ # - min_quarterword { to take an eight_bits item out of a quarterword }
define hi(#) ≡ # + min_halfword { to put a sixteen-bit item into a halfword }
define ho(#) ≡ # - min_halfword { to take a sixteen-bit item from a halfword }
```

131. The reader should study the following definitions closely:

```
define sc ≡ int { scaled data is equivalent to integer }
⟨Types in the outer block 18⟩ +=
quarterword = min_quarterword .. max_quarterword; { 1/4 of a word }
halfword = min_halfword .. max_halfword; { 1/2 of a word }
two_choices = 1 .. 2; { used when there are two variants in a record }
four_choices = 1 .. 4; { used when there are four variants in a record }
two_halves = packed record rh: halfword;
  case two_choices of
    1: (lh : halfword);
    2: (b0 : quarterword; b1 : quarterword);
  end;
four_quarters = packed record b0: quarterword;
  b1: quarterword;
  b2: quarterword;
  b3: quarterword;
end;
memory_word = record
  case four_choices of
    1: (int : integer);
    2: (gr : glue_ratio);
    3: (hh : two_halves);
    4: (qqqq : four_quarters);
  end;
word_file = file of memory_word;
```

132. When debugging, we may want to print a *memory_word* without knowing what type it is; so we print it in all modes.

```
debug procedure print_word(w : memory_word); { prints w in all ways }
begin print_int(w.int); print_char("□");
print_scaled(w.sc); print_char("□");
print_scaled(round(unity * float(w.gr))); print_ln;
print_int(w.hh.lh); print_char("="); print_int(w.hh.b0); print_char(":"); print_int(w.hh.b1);
print_char(";"); print_int(w.hh.rh); print_char("□");
print_int(w.qqqq.b0); print_char(":"); print_int(w.qqqq.b1); print_char(":"); print_int(w.qqqq.b2);
print_char(";"); print_int(w.qqqq.b3);
end;
gubed
```

133. Dynamic memory allocation. The TeX system does nearly all of its own memory allocation, so that it can readily be transported into environments that do not have automatic facilities for strings, garbage collection, etc., and so that it can be in control of what error messages the user receives. The dynamic storage requirements of TeX are handled by providing a large array *mem* in which consecutive blocks of words are used as nodes by the TeX routines.

Pointer variables are indices into this array, or into another array called *eqtb* that will be explained later. A pointer variable might also be a special flag that lies outside the bounds of *mem*, so we allow pointers to assume any *halfword* value. The minimum halfword value represents a null pointer. TeX does not assume that *mem*[*null*] exists.

define *pointer* \equiv *halfword* { a flag or a location in *mem* or *eqtb* }

define *null* \equiv *min_halfword* { the null pointer }

\langle Global variables 13 $\rangle + \equiv$

temp_ptr: *pointer*; { a pointer variable for occasional emergency use }

134. The *mem* array is divided into two regions that are allocated separately, but the dividing line between these two regions is not fixed; they grow together until finding their “natural” size in a particular job. Locations less than or equal to *lo_mem_max* are used for storing variable-length records consisting of two or more words each. This region is maintained using an algorithm similar to the one described in exercise 2.5–19 of *The Art of Computer Programming*. However, no size field appears in the allocated nodes; the program is responsible for knowing the relevant size when a node is freed. Locations greater than or equal to *hi_mem_min* are used for storing one-word records; a conventional AVAIL stack is used for allocation in this region.

Locations of *mem* between *mem_bot* and *mem_top* may be dumped as part of preloaded format files, by the INITEX preprocessor. Production versions of TeX may extend the memory at both ends in order to provide more space; locations between *mem_min* and *mem_bot* are always used for variable-size nodes, and locations between *mem_top* and *mem_max* are always used for single-word nodes.

The key pointers that govern *mem* allocation have a prescribed order:

$$null \leq mem_min \leq mem_bot < lo_mem_max < hi_mem_min < mem_top \leq mem_end \leq mem_max.$$

Empirical tests show that the present implementation of TeX tends to spend about 9% of its running time allocating nodes, and about 6% deallocating them after their use.

\langle Global variables 13 $\rangle + \equiv$

mem: **array** [*mem_min* .. *mem_max*] **of** *memory_word*; { the big dynamic storage area }

lo_mem_max: *pointer*; { the largest location of variable-size memory in use }

hi_mem_min: *pointer*; { the smallest location of one-word memory in use }

135. In order to study the memory requirements of particular applications, it is possible to prepare a version of TeX that keeps track of current and maximum memory usage. When code between the delimiters **stat** ... **tats** is not “commented out,” TeX will run a bit slower but it will report these statistics when *tracing_stats* is sufficiently large.

\langle Global variables 13 $\rangle + \equiv$

var_used, *dyn_used*: *integer*; { how much memory is in use }

136. Let's consider the one-word memory region first, since it's the simplest. The pointer variable *mem_end* holds the highest-numbered location of *mem* that has ever been used. The free locations of *mem* that occur between *hi_mem_min* and *mem_end*, inclusive, are of type *two_halves*, and we write *info(p)* and *link(p)* for the *lh* and *rh* fields of *mem[p]* when it is of this type. The single-word free locations form a linked list

avail, *link(avail)*, *link(link(avail))*, ...

terminated by *null*.

```
define link(#)  $\equiv$  mem[#].hh.rh  { the link field of a memory word }
define info(#)  $\equiv$  mem[#].hh.lh  { the info field of a memory word }
⟨Global variables 13⟩ +=
avail: pointer;  { head of the list of available one-word nodes }
mem_end: pointer;  { the last one-word node used in mem }
```

137. If memory is exhausted, it might mean that the user has forgotten a right brace. We will define some procedures later that try to help pinpoint the trouble.

```
⟨Declare the procedure called show_token_list 314⟩
⟨Declare the procedure called runaway 328⟩
```

138. The function *get_avail* returns a pointer to a new one-word node whose *link* field is null. However, TeX will halt if there is no more room left.

If the available-space list is empty, i.e., if *avail* = *null*, we try first to increase *mem_end*. If that cannot be done, i.e., if *mem_end* = *mem_max*, we try to decrease *hi_mem_min*. If that cannot be done, i.e., if *hi_mem_min* = *lo_mem_max* + 1, we have to quit.

```
function get_avail: pointer;  { single-word node allocation }
var p: pointer;  { the new node being got }
begin p  $\leftarrow$  avail;  { get top location in the avail stack }
if p  $\neq$  null then avail  $\leftarrow$  link(avail)  { and pop it off }
else if mem_end < mem_max then  { or go into virgin territory }
  begin incr(mem_end); p  $\leftarrow$  mem_end;
  end
else begin decr(hi_mem_min); p  $\leftarrow$  hi_mem_min;
  if hi_mem_min  $\leq$  lo_mem_max then
    begin runaway;  { if memory is exhausted, display possible runaway text }
    overflow("main_memory_size", mem_max + 1 - mem_min);  { quit; all one-word nodes are busy }
    end;
  end;
  link(p)  $\leftarrow$  null;  { provide an oft-desired initialization of the new node }
stat incr(dyn_used); tats  { maintain statistics }
get_avail  $\leftarrow$  p;
end;
```

139. Conversely, a one-word node is recycled by calling *free_avail*. This routine is part of TeX's "inner loop," so we want it to be fast.

```
define free_avail(#)  $\equiv$   { single-word node liberation }
  begin link(#)  $\leftarrow$  avail; avail  $\leftarrow$  #;
  stat decr(dyn_used); tats
  end
```

140. There's also a *fast_get_avail* routine, which saves the procedure-call overhead at the expense of extra programming. This routine is used in the places that would otherwise account for the most calls of *get_avail*.

```
define fast_get_avail(#)  $\equiv$ 
  begin #  $\leftarrow$  avail; { avoid get_avail if possible, to save time }
  if # = null then #  $\leftarrow$  get_avail
  else begin avail  $\leftarrow$  link(#); link(#)  $\leftarrow$  null;
    stat incr(dyn_used); tats
  end;
end
```

141. The procedure *flush_list*(*p*) frees an entire linked list of one-word nodes that starts at position *p*.

```
procedure flush_list(p : pointer); { makes list of single-word nodes available }
var q, r: pointer; { list traversers }
begin if p  $\neq$  null then
  begin r  $\leftarrow$  p;
  repeat q  $\leftarrow$  r; r  $\leftarrow$  link(r);
    stat decr(dyn_used); tats
  until r = null; { now q is the last node on the list }
  link(q)  $\leftarrow$  avail; avail  $\leftarrow$  p;
  end;
end;
```

142. The available-space list that keeps track of the variable-size portion of *mem* is a nonempty, doubly-linked circular list of empty nodes, pointed to by the roving pointer *rover*.

Each empty node has size 2 or more; the first word contains the special value *max_halfword* in its *link* field and the size in its *info* field; the second word contains the two pointers for double linking.

Each nonempty node also has size 2 or more. Its first word is of type *two_halves*, and its *link* field is never equal to *max_halfword*. Otherwise there is complete flexibility with respect to the contents of its other fields and its other words.

(We require *mem_max* < *max_halfword* because terrible things can happen when *max_halfword* appears in the *link* field of a nonempty node.)

```
define empty_flag  $\equiv$  max_halfword { the link of an empty variable-size node }
define is_empty(#)  $\equiv$  (link(#) = empty_flag) { tests for empty node }
define node_size  $\equiv$  info { the size field in empty variable-size nodes }
define llink(#)  $\equiv$  info(# + 1) { left link in doubly-linked list of empty nodes }
define rlink(#)  $\equiv$  link(# + 1) { right link in doubly-linked list of empty nodes }
```

\langle Global variables 13 $\rangle + \equiv$

rover: *pointer*; { points to some node in the list of empties }

143. A call to *get_node* with argument *s* returns a pointer to a new node of size *s*, which must be 2 or more. The *link* field of the first word of this new node is set to null. An overflow stop occurs if no suitable space exists.

If *get_node* is called with $s = 2^{30}$, it simply merges adjacent free areas and returns the value *max_halfword*.

```

function get_node(s : integer): pointer; { variable-size node allocation }
  label found, exit, restart;
  var p: pointer; { the node currently under inspection }
      q: pointer; { the node physically after node p }
      r: integer; { the newly allocated node, or a candidate for this honor }
      t: integer; { temporary register }
  begin restart: p ← rover; { start at some free node in the ring }
  repeat ⟨ Try to allocate within node p and its physical successors, and goto found if allocation was
    possible 145 ⟩;
    p ← rlink(p); { move to the next node in the ring }
  until p = rover; { repeat until the whole list has been traversed }
  if s = '10000000000 then
    begin get_node ← max_halfword; return;
    end;
  if lo_mem_max + 2 < hi_mem_min then
    if lo_mem_max + 2 ≤ mem_bot + max_halfword then
      ⟨ Grow more variable-size memory and goto restart 144 ⟩;
      overflow("main_memory_size", mem_max + 1 − mem_min); { sorry, nothing satisfactory is left }
    found: link(r) ← null; { this node is now nonempty }
    stat var_used ← var_used + s; { maintain usage statistics }
    tats
      get_node ← r;
    exit: end;

```

144. The lower part of *mem* grows by 1000 words at a time, unless we are very close to going under. When it grows, we simply link a new node into the available-space list. This method of controlled growth helps to keep the *mem* usage consecutive when TeX is implemented on “virtual memory” systems.

```

⟨ Grow more variable-size memory and goto restart 144 ⟩ ≡
  begin if hi_mem_min − lo_mem_max ≥ 1998 then t ← lo_mem_max + 1000
  else t ← lo_mem_max + 1 + (hi_mem_min − lo_mem_max) div 2; { lo_mem_max + 2 ≤ t < hi_mem_min }
  p ← llink(rover); q ← lo_mem_max; rlink(p) ← q; llink(rover) ← q;
  if t > mem_bot + max_halfword then t ← mem_bot + max_halfword;
  rlink(q) ← rover; llink(q) ← p; link(q) ← empty_flag; node_size(q) ← t − lo_mem_max;
  lo_mem_max ← t; link(lo_mem_max) ← null; info(lo_mem_max) ← null; rover ← q; goto restart;
  end

```

This code is used in section 143.

145. Empirical tests show that the routine in this section performs a node-merging operation about 0.75 times per allocation, on the average, after which it finds that $r > p + 1$ about 95% of the time.

\langle Try to allocate within node p and its physical successors, and **goto** *found* if allocation was possible 145 $\rangle \equiv$

```

 $q \leftarrow p + \text{node\_size}(p);$  { find the physical successor }
while is_empty( $q$ ) do { merge node  $p$  with node  $q$  }
  begin  $t \leftarrow \text{rlink}(q);$ 
  if  $q = \text{rover}$  then  $\text{rover} \leftarrow t;$ 
   $\text{llink}(t) \leftarrow \text{llink}(q);$   $\text{rlink}(\text{llink}(q)) \leftarrow t;$ 
   $q \leftarrow q + \text{node\_size}(q);$ 
  end;
 $r \leftarrow q - s;$ 
if  $r > p + 1$  then  $\langle$  Allocate from the top of node  $p$  and goto found 146  $\rangle;$ 
if  $r = p$  then
  if  $\text{rlink}(p) \neq p$  then  $\langle$  Allocate entire node  $p$  and goto found 147  $\rangle;$ 
   $\text{node\_size}(p) \leftarrow q - p$  { reset the size in case it grew }

```

This code is used in section 143.

146. \langle Allocate from the top of node p and **goto** *found* 146 $\rangle \equiv$

```

begin  $\text{node\_size}(p) \leftarrow r - p;$  { store the remaining size }
 $\text{rover} \leftarrow p;$  { start searching here next time }
goto found;
end

```

This code is used in section 145.

147. Here we delete node p from the ring, and let *rover* rove around.

\langle Allocate entire node p and **goto** *found* 147 $\rangle \equiv$

```

begin  $\text{rover} \leftarrow \text{rlink}(p);$   $t \leftarrow \text{llink}(p);$   $\text{llink}(\text{rover}) \leftarrow t;$   $\text{rlink}(t) \leftarrow \text{rover};$  goto found;
end

```

This code is used in section 145.

148. Conversely, when some variable-size node p of size s is no longer needed, the operation *free_node*(p, s) will make its words available, by inserting p as a new empty node just before where *rover* now points.

```

procedure free_node( $p : \text{pointer}; s : \text{halfword}$ ); { variable-size node liberation }
  var  $q : \text{pointer};$  {  $\text{llink}(\text{rover})$  }
  begin  $\text{node\_size}(p) \leftarrow s;$   $\text{link}(p) \leftarrow \text{empty\_flag};$   $q \leftarrow \text{llink}(\text{rover});$   $\text{llink}(p) \leftarrow q;$   $\text{rlink}(p) \leftarrow \text{rover};$ 
    { set both links }
   $\text{llink}(\text{rover}) \leftarrow p;$   $\text{rlink}(q) \leftarrow p;$  { insert  $p$  into the ring }
  stat  $\text{var\_used} \leftarrow \text{var\_used} - s;$  tats { maintain statistics }
end;

```


149. Just before INITEX writes out the memory, it sorts the doubly linked available space list. The list is probably very short at such times, so a simple insertion sort is used. The smallest available location will be pointed to by *rover*, the next-smallest by *rlink(rover)*, etc.

```

init procedure sort_avail; { sorts the available variable-size nodes by location }
var p, q, r: pointer; { indices into mem }
      old_rover: pointer; { initial rover setting }
begin p  $\leftarrow$  get_node('10000000000'); { merge adjacent free areas }
p  $\leftarrow$  rlink(rover); rlink(rover)  $\leftarrow$  max_halfword; old_rover  $\leftarrow$  rover;
while p  $\neq$  old_rover do {Sort p into the list starting at rover and advance p to rlink(p) 150};
p  $\leftarrow$  rover;
while rlink(p)  $\neq$  max_halfword do
  begin llink(rlink(p))  $\leftarrow$  p; p  $\leftarrow$  rlink(p);
  end;
rlink(p)  $\leftarrow$  rover; llink(rover)  $\leftarrow$  p;
end;
tini

```

150. The following **while** loop is guaranteed to terminate, since the list that starts at *rover* ends with *max_halfword* during the sorting procedure.

```

{Sort p into the list starting at rover and advance p to rlink(p) 150}  $\equiv$ 
if p < rover then
  begin q  $\leftarrow$  p; p  $\leftarrow$  rlink(q); rlink(q)  $\leftarrow$  rover; rover  $\leftarrow$  q;
  end
else begin q  $\leftarrow$  rover;
  while rlink(q) < p do q  $\leftarrow$  rlink(q);
  r  $\leftarrow$  rlink(p); rlink(p)  $\leftarrow$  rlink(q); rlink(q)  $\leftarrow$  p; p  $\leftarrow$  r;
  end

```

This code is used in section 149.

151. Data structures for boxes and their friends. From the computer’s standpoint, T_EX’s chief mission is to create horizontal and vertical lists. We shall now investigate how the elements of these lists are represented internally as nodes in the dynamic memory.

A horizontal or vertical list is linked together by *link* fields in the first word of each node. Individual nodes represent boxes, glue, penalties, or special things like discretionary hyphens; because of this variety, some nodes are longer than others, and we must distinguish different kinds of nodes. We do this by putting a ‘*type*’ field in the first word, together with the link and an optional ‘*subtype*’.

```
define  type(#) ≡ mem[#].hh.b0    { identifies what kind of node this is }
define  subtype(#) ≡ mem[#].hh.b1  { secondary identification in some cases }
```

152. A *char_node*, which represents a single character, is the most important kind of node because it accounts for the vast majority of all boxes. Special precautions are therefore taken to ensure that a *char_node* does not take up much memory space. Every such node is one word long, and in fact it is identifiable by this property, since other kinds of nodes have at least two words, and they appear in *mem* locations less than *hi_mem_min*. This makes it possible to omit the *type* field in a *char_node*, leaving us room for two bytes that identify a *font* and a *character* within that font.

Note that the format of a *char_node* allows for up to 256 different fonts and up to 256 characters per font; but most implementations will probably limit the total number of fonts to fewer than 75 per job, and most fonts will stick to characters whose codes are less than 128 (since higher codes are more difficult to access on most keyboards).

Extensions of T_EX intended for oriental languages will need even more than 256×256 possible characters, when we consider different sizes and styles of type. It is suggested that Chinese and Japanese fonts be handled by representing such characters in two consecutive *char_node* entries: The first of these has *font* = *font_base*, and its *link* points to the second; the second identifies the font and the character dimensions. The saving feature about oriental characters is that most of them have the same box dimensions. The *character* field of the first *char_node* is a “*charext*” that distinguishes between graphic symbols whose dimensions are identical for typesetting purposes. (See the METAFONT manual.) Such an extension of T_EX would not be difficult; further details are left to the reader.

In order to make sure that the *character* code fits in a quarterword, T_EX adds the quantity *min_quarterword* to the actual code.

Character nodes appear only in horizontal lists, never in vertical lists.

```
define  is_char_node(#) ≡ (# ≥ hi_mem_min)  { does the argument point to a char_node? }
define  font ≡ type    { the font code in a char_node }
define  character ≡ subtype { the character code in a char_node }
```

153. An *hlist_node* stands for a box that was made from a horizontal list. Each *hlist_node* is seven words long, and contains the following fields (in addition to the mandatory *type* and *link*, which we shall not mention explicitly when discussing the other node types): The *height* and *width* and *depth* are scaled integers denoting the dimensions of the box. There is also a *shift_amount* field, a scaled integer indicating how much this box should be lowered (if it appears in a horizontal list), or how much it should be moved to the right (if it appears in a vertical list). There is a *list_ptr* field, which points to the beginning of the list from which this box was fabricated; if *list_ptr* is *null*, the box is empty. Finally, there are three fields that represent the setting of the glue: *glue_set(p)* is a word of type *glue_ratio* that represents the proportionality constant for glue setting; *glue_sign(p)* is *stretching* or *shrinking* or *normal* depending on whether or not the glue should stretch or shrink or remain rigid; and *glue_order(p)* specifies the order of infinity to which glue setting applies (*normal*, *fil*, *fill*, or *filll*). The *subtype* field is not used in TeX. In ε -TeX the *subtype* field records the box direction mode *box_lr*.

```

define hlist_node = 0 { type of hlist nodes }
define box_node_size = 7 { number of words to allocate for a box node }
define width_offset = 1 { position of width field in a box node }
define depth_offset = 2 { position of depth field in a box node }
define height_offset = 3 { position of height field in a box node }
define width(#) $\equiv$  mem[# + width_offset].sc { width of the box, in sp }
define depth(#) $\equiv$  mem[# + depth_offset].sc { depth of the box, in sp }
define height(#) $\equiv$  mem[# + height_offset].sc { height of the box, in sp }
define shift_amount(#) $\equiv$  mem[# + 4].sc { repositioning distance, in sp }
define list_offset = 5 { position of list_ptr field in a box node }
define list_ptr(#) $\equiv$  link[# + list_offset] { beginning of the list inside the box }
define glue_order(#) $\equiv$  subtype[# + list_offset] { applicable order of infinity }
define glue_sign(#) $\equiv$  type[# + list_offset] { stretching or shrinking }
define normal = 0 { the most common case when several cases are named }
define stretching = 1 { glue setting applies to the stretch components }
define shrinking = 2 { glue setting applies to the shrink components }
define glue_offset = 6 { position of glue_set in a box node }
define glue_set(#) $\equiv$  mem[# + glue_offset].gr { a word of type glue_ratio for glue setting }

```

154. The *new_null_box* function returns a pointer to an *hlist_node* in which all subfields have the values corresponding to ‘\hbox{ }’. (The *subtype* field is set to *min_quarterword*, for historic reasons that are no longer relevant.)

```

function new_null_box: pointer; { creates a new box node }
  var p: pointer; { the new node }
  begin p  $\leftarrow$  get_node(box_node_size); type(p)  $\leftarrow$  hlist_node; subtype(p)  $\leftarrow$  min_quarterword;
  width(p)  $\leftarrow$  0; depth(p)  $\leftarrow$  0; height(p)  $\leftarrow$  0; shift_amount(p)  $\leftarrow$  0; list_ptr(p)  $\leftarrow$  null;
  glue_sign(p)  $\leftarrow$  normal; glue_order(p)  $\leftarrow$  normal; set_glue_ratio_zero(glue_set(p)); new_null_box  $\leftarrow$  p;
  end;

```

155. A *vlist_node* is like an *hlist_node* in all respects except that it contains a vertical list.

```

define vlist_node = 1 { type of vlist nodes }

```

156. A *rule_node* stands for a solid black rectangle; it has *width*, *depth*, and *height* fields just as in an *hlist_node*. However, if any of these dimensions is -2^{30} , the actual value will be determined by running the rule up to the boundary of the innermost enclosing box. This is called a “running dimension.” The *width* is never running in an *hlist*; the *height* and *depth* are never running in a *vlist*.

```
define rule_node = 2 { type of rule nodes }
define rule_node_size = 4 { number of words to allocate for a rule node }
define null_flag  $\equiv -'10000000000$  {  $-2^{30}$ , signifies a missing item }
define is_running( $\#$ )  $\equiv (\# = \text{null\_flag})$  { tests for a running dimension }
```

157. A new rule node is delivered by the *new_rule* function. It makes all the dimensions “running,” so you have to change the ones that are not allowed to run.

```
function new_rule: pointer;
var p: pointer; { the new node }
begin p  $\leftarrow$  get_node(rule_node_size); type(p)  $\leftarrow$  rule_node; subtype(p)  $\leftarrow$  0; { the subtype is not used }
width(p)  $\leftarrow$  null_flag; depth(p)  $\leftarrow$  null_flag; height(p)  $\leftarrow$  null_flag; new_rule  $\leftarrow$  p;
end;
```

158. Insertions are represented by *ins_node* records, where the *subtype* indicates the corresponding box number. For example, ‘\insert 250’ leads to an *ins_node* whose *subtype* is $250 + \text{min_quarterword}$. The *height* field of an *ins_node* is slightly misnamed; it actually holds the natural height plus depth of the vertical list being inserted. The *depth* field holds the *split_max_depth* to be used in case this insertion is split, and the *split_top_ptr* points to the corresponding *split_top_skip*. The *float_cost* field holds the *floating_penalty* that will be used if this insertion floats to a subsequent page after a split insertion of the same class. There is one more field, the *ins_ptr*, which points to the beginning of the *vlist* for the insertion.

```
define ins_node = 3 { type of insertion nodes }
define ins_node_size = 5 { number of words to allocate for an insertion }
define float_cost( $\#$ )  $\equiv \text{mem}[\# + 1].\text{int}$  { the floating_penalty to be used }
define ins_ptr( $\#$ )  $\equiv \text{info}(\# + 4)$  { the vertical list to be inserted }
define split_top_ptr( $\#$ )  $\equiv \text{link}(\# + 4)$  { the split_top_skip to be used }
```

159. A *mark_node* has a *mark_ptr* field that points to the reference count of a token list that contains the user’s \mark text. In addition there is a *mark_class* field that contains the mark class.

```
define mark_node = 4 { type of a mark node }
define small_node_size = 2 { number of words to allocate for most node types }
define mark_ptr( $\#$ )  $\equiv \text{link}(\# + 1)$  { head of the token list for a mark }
define mark_class( $\#$ )  $\equiv \text{info}(\# + 1)$  { the mark class }
```

160. An *adjust_node*, which occurs only in horizontal lists, specifies material that will be moved out into the surrounding vertical list; i.e., it is used to implement TeX’s ‘\vadjust’ operation. The *adjust_ptr* field points to the *vlist* containing this material.

```
define adjust_node = 5 { type of an adjust node }
define adjust_pre  $\equiv$  subtype {  $i \neq 0$  =  $i$  pre-adjustment }
{ append_list is used to append a list to tail }
define append_list( $\#$ )  $\equiv$ 
begin link(tail)  $\leftarrow$  link( $\#$ ); append_list_end
define append_list_end( $\#$ )  $\equiv$  tail  $\leftarrow$   $\#$ ;
end
define adjust_ptr( $\#$ )  $\equiv \text{mem}[\# + 1].\text{int}$  { vertical list to be moved out of horizontal list }
```

161. A *ligature_node*, which occurs only in horizontal lists, specifies a character that was fabricated from the interaction of two or more actual characters. The second word of the node, which is called the *lig_char* word, contains *font* and *character* fields just as in a *char_node*. The characters that generated the ligature have not been forgotten, since they are needed for diagnostic messages and for hyphenation; the *lig_ptr* field points to a linked list of character nodes for all original characters that have been deleted. (This list might be empty if the characters that generated the ligature were retained in other nodes.)

The *subtype* field is 0, plus 2 and/or 1 if the original source of the ligature included implicit left and/or right boundaries.

```
define ligature_node = 6 { type of a ligature node }
define lig_char(#) ≡ # + 1 { the word where the ligature is to be found }
define lig_ptr(#) ≡ link(lig_char(#)) { the list of characters }
```

162. The *new_ligature* function creates a ligature node having given contents of the *font*, *character*, and *lig_ptr* fields. We also have a *new_lig_item* function, which returns a two-word node having a given *character* field. Such nodes are used for temporary processing as ligatures are being created.

```
function new_ligature(f, c : quarterword; q : pointer): pointer;
var p : pointer; { the new node }
begin p ← get_node(small_node_size); type(p) ← ligature_node; font(lig_char(p)) ← f;
character(lig_char(p)) ← c; lig_ptr(p) ← q; subtype(p) ← 0; new_ligature ← p;
end;

function new_lig_item(c : quarterword): pointer;
var p : pointer; { the new node }
begin p ← get_node(small_node_size); character(p) ← c; lig_ptr(p) ← null; new_lig_item ← p;
end;
```

163. A *disc_node*, which occurs only in horizontal lists, specifies a “discretionary” line break. If such a break occurs at node *p*, the text that starts at *pre_break*(*p*) will precede the break, the text that starts at *post_break*(*p*) will follow the break, and text that appears in the next *replace_count*(*p*) nodes will be ignored. For example, an ordinary discretionary hyphen, indicated by ‘\–’, yields a *disc_node* with *pre_break* pointing to a *char_node* containing a hyphen, *post_break* = *null*, and *replace_count* = 0. All three of the discretionary texts must be lists that consist entirely of character, kern, box, rule, and ligature nodes.

If *pre_break*(*p*) = *null*, the *ex_hyphen_penalty* will be charged for this break. Otherwise the *hyphen_penalty* will be charged. The texts will actually be substituted into the list by the line-breaking algorithm if it decides to make the break, and the discretionary node will disappear at that time; thus, the output routine sees only discretionaries that were not chosen.

```
define disc_node = 7 { type of a discretionary node }
define replace_count ≡ subtype { how many subsequent nodes to replace }
define pre_break ≡ llink { text that precedes a discretionary break }
define post_break ≡ rlink { text that follows a discretionary break }

function new_disc: pointer; { creates an empty disc_node }
var p : pointer; { the new node }
begin p ← get_node(small_node_size); type(p) ← disc_node; replace_count(p) ← 0; pre_break(p) ← null;
post_break(p) ← null; new_disc ← p;
end;
```

164. A *whatsit_node* is a wild card reserved for extensions to TeX. The *subtype* field in its first word says what ‘*whatsit*’ it is, and implicitly determines the node size (which must be 2 or more) and the format of the remaining words. When a *whatsit_node* is encountered in a list, special actions are invoked; knowledgeable people who are careful not to mess up the rest of TeX are able to make TeX do new things by adding code at the end of the program. For example, there might be a ‘TeXnicolor’ extension to specify different colors of ink, and the *whatsit_node* might contain the desired parameters.

The present implementation of TeX treats the features associated with ‘\write’ and ‘\special’ as if they were extensions, in order to illustrate how such routines might be coded. We shall defer further discussion of extensions until the end of this program.

```
define whatsit_node = 8 { type of special extension nodes }
```

165. A *math_node*, which occurs only in horizontal lists, appears before and after mathematical formulas. The *subtype* field is *before* before the formula and *after* after it. There is a *width* field, which represents the amount of surrounding space inserted by \mathsurround.

In addition a *math_node* with *subtype* > *after* and *width* = 0 will be (ab)used to record a regular *math_node* reinserted after being discarded at a line break or one of the text direction primitives (\beginL, \endL, \beginR, and \endR).

```
define math_node = 9 { type of a math node }
define before = 0 { subtype for math node that introduces a formula }
define after = 1 { subtype for math node that winds up a formula }
define M_code = 2
define begin_M_code = M_code + before { subtype for \beginM node }
define end_M_code = M_code + after { subtype for \endM node }
define L_code = 4
define begin_L_code = L_code + begin_M_code { subtype for \beginL node }
define end_L_code = L_code + end_M_code { subtype for \endL node }
define R_code = L_code + L_code
define begin_R_code = R_code + begin_M_code { subtype for \beginR node }
define end_R_code = R_code + end_M_code { subtype for \endR node }
define end_LR(#)  $\equiv$  odd(subtype(#))
define end_LR_type(#)  $\equiv$  (L_code * (subtype(#) div L_code) + end_M_code)
define begin_LR_type(#)  $\equiv$  (# - after + before)
```

```
function new_math(w : scaled; s : small_number): pointer;
```

```
  var p: pointer; { the new node }
  begin p  $\leftarrow$  get_node(small_node_size); type(p)  $\leftarrow$  math_node; subtype(p)  $\leftarrow$  s; width(p)  $\leftarrow$  w;
  new_math  $\leftarrow$  p;
end;
```

166. TeX makes use of the fact that *hlist_node*, *vlist_node*, *rule_node*, *ins_node*, *mark_node*, *adjust_node*, *ligature_node*, *disc_node*, *whatsit_node*, and *math_node* are at the low end of the type codes, by permitting a break at glue in a list if and only if the *type* of the previous node is less than *math_node*. Furthermore, a node is discarded after a break if its type is *math_node* or more.

```
define precedes_break(#)  $\equiv$  (type(#) < math_node)
define non_discardable(#)  $\equiv$  (type(#) < math_node)
```

167. A *glue_node* represents glue in a list. However, it is really only a pointer to a separate glue specification, since TeX makes use of the fact that many essentially identical nodes of glue are usually present. If p points to a *glue_node*, *glue_ptr*(p) points to another packet of words that specify the stretch and shrink components, etc.

Glue nodes also serve to represent leaders; the *subtype* is used to distinguish between ordinary glue (which is called *normal*) and the three kinds of leaders (which are called *a.leaders*, *c.leaders*, and *x.leaders*). The *leader_ptr* field points to a rule node or to a box node containing the leaders; it is set to *null* in ordinary glue nodes.

Many kinds of glue are computed from TeX's “skip” parameters, and it is helpful to know which parameter has led to a particular glue node. Therefore the *subtype* is set to indicate the source of glue, whenever it originated as a parameter. We will be defining symbolic names for the parameter numbers later (e.g., *line_skip_code* = 0, *baseline_skip_code* = 1, etc.); it suffices for now to say that the *subtype* of parametric glue will be the same as the parameter number, plus one.

In math formulas there are two more possibilities for the *subtype* in a glue node: *mu_glue* denotes an `\mskip` (where the units are scaled mu instead of scaled pt); and *cond_math_glue* denotes the ‘`\nonscript`’ feature that cancels the glue node immediately following if it appears in a subscript.

```
define glue_node = 10 { type of node that points to a glue specification }
define cond_math_glue = 98 { special subtype to suppress glue in the next node }
define mu_glue = 99 { subtype for math glue }
define a.leaders = 100 { subtype for aligned leaders }
define c.leaders = 101 { subtype for centered leaders }
define x.leaders = 102 { subtype for expanded leaders }
define glue_ptr ≡ llink { pointer to a glue specification }
define leader_ptr ≡ rlink { pointer to box or rule node for leaders }
```

168. A glue specification has a halfword reference count in its first word, representing *null* plus the number of glue nodes that point to it (less one). Note that the reference count appears in the same position as the *link* field in list nodes; this is the field that is initialized to *null* when a node is allocated, and it is also the field that is flagged by *empty_flag* in empty nodes.

Glue specifications also contain three *scaled* fields, for the *width*, *stretch*, and *shrink* dimensions. Finally, there are two one-byte fields called *stretch_order* and *shrink_order*; these contain the orders of infinity (*normal*, *fil*, *fill*, or *filll*) corresponding to the stretch and shrink values.

```
define glue_spec_size = 4 { number of words to allocate for a glue specification }
define glue_ref_count( # ) ≡ link( # ) { reference count of a glue specification }
define stretch( # ) ≡ mem[ # + 2 ].sc { the stretchability of this glob of glue }
define shrink( # ) ≡ mem[ # + 3 ].sc { the shrinkability of this glob of glue }
define stretch_order ≡ type { order of infinity for stretching }
define shrink_order ≡ subtype { order of infinity for shrinking }
define fil = 1 { first-order infinity }
define fill = 2 { second-order infinity }
define filll = 3 { third-order infinity }
```

(Types in the outer block 18) +≡

```
glue_ord = normal .. filll; { infinity to the 0, 1, 2, or 3 power }
```

169. Here is a function that returns a pointer to a copy of a glue spec. The reference count in the copy is *null*, because there is assumed to be exactly one reference to the new specification.

```
function new_spec(p : pointer): pointer; { duplicates a glue specification }
  var q: pointer; { the new spec }
  begin q  $\leftarrow$  get_node(glue_spec_size);
  mem[q]  $\leftarrow$  mem[p]; glue_ref_count(q)  $\leftarrow$  null;
  width(q)  $\leftarrow$  width(p); stretch(q)  $\leftarrow$  stretch(p); shrink(q)  $\leftarrow$  shrink(p); new_spec  $\leftarrow$  q;
  end;
```

170. And here's a function that creates a glue node for a given parameter identified by its code number; for example, *new_param_glue*(*line_skip_code*) returns a pointer to a glue node for the current `\lineskip`.

```
function new_param_glue(n : small_number): pointer;
  var p: pointer; { the new node }
  q: pointer; { the glue specification }
  begin p  $\leftarrow$  get_node(small_node_size); type(p)  $\leftarrow$  glue_node; subtype(p)  $\leftarrow$  n + 1; leader_ptr(p)  $\leftarrow$  null;
  q  $\leftarrow$  (Current mem equivalent of glue parameter number n 242); glue_ptr(p)  $\leftarrow$  q;
  incr(glue_ref_count(q)); new_param_glue  $\leftarrow$  p;
  end;
```

171. Glue nodes that are more or less anonymous are created by *new_glue*, whose argument points to a glue specification.

```
function new_glue(q : pointer): pointer;
  var p: pointer; { the new node }
  begin p  $\leftarrow$  get_node(small_node_size); type(p)  $\leftarrow$  glue_node; subtype(p)  $\leftarrow$  normal;
  leader_ptr(p)  $\leftarrow$  null; glue_ptr(p)  $\leftarrow$  q; incr(glue_ref_count(q)); new_glue  $\leftarrow$  p;
  end;
```

172. Still another subroutine is needed: This one is sort of a combination of *new_param_glue* and *new_glue*. It creates a glue node for one of the current glue parameters, but it makes a fresh copy of the glue specification, since that specification will probably be subject to change, while the parameter will stay put. The global variable *temp_ptr* is set to the address of the new spec.

```
function new_skip_param(n : small_number): pointer;
  var p: pointer; { the new node }
  begin temp_ptr  $\leftarrow$  new_spec((Current mem equivalent of glue parameter number n 242));
  p  $\leftarrow$  new_glue(temp_ptr); glue_ref_count(temp_ptr)  $\leftarrow$  null; subtype(p)  $\leftarrow$  n + 1; new_skip_param  $\leftarrow$  p;
  end;
```


173. A *kern_node* has a *width* field to specify a (normally negative) amount of spacing. This spacing correction appears in horizontal lists between letters like A and V when the font designer said that it looks better to move them closer together or further apart. A kern node can also appear in a vertical list, when its ‘*width*’ denotes additional spacing in the vertical direction. The *subtype* is either *normal* (for kerns inserted from font information or math mode calculations) or *explicit* (for kerns inserted from `\kern` and `\/` commands) or *acc_kern* (for kerns inserted from non-math accents) or *mu_glue* (for kerns inserted from `\mkern` specifications in math formulas).

```

define kern_node = 11 { type of a kern node }
define explicit = 1 { subtype of kern nodes from \kern and \/ }
define acc_kern = 2 { subtype of kern nodes from accents }
define auto_kern = 3 { subtype of kern nodes created by get_auto_kern }
    { memory structure for marginal kerns }
define margin_kern_node = 40
define margin_kern_node_size = 3
define margin_char(#) ≡ info(# + 2)
    { subtype of marginal kerns }
define left_side ≡ 0
define right_side ≡ 1
    { base for lp/rp/ef codes starts from 2: 0 for hyphen_char, 1 for skew_char }
define lp_code_base ≡ 2
define rp_code_base ≡ 3
define ef_code_base ≡ 4
define tag_code ≡ 5
define kn_bs_code_base ≡ 7
define st_bs_code_base ≡ 8
define sh_bs_code_base ≡ 9
define kn_bc_code_base ≡ 10
define kn_ac_code_base ≡ 11
define no_lig_code ≡ 6
define max_hlist_stack = 512 { maximum fill level for hlist_stack }
    { maybe good if larger than 2 * max_quarterword, so that box nesting level would overflow first }

```

174. The *new_kern* function creates a kern node having a given width.

```

function new_kern(w : scaled): pointer;
  var p: pointer; { the new node }
  begin p ← get_node(small_node_size); type(p) ← kern_node; subtype(p) ← normal; width(p) ← w;
  new_kern ← p;
end;

```

175. A *penalty_node* specifies the penalty associated with line or page breaking, in its *penalty* field. This field is a fullword integer, but the full range of integer values is not used: Any penalty ≥ 10000 is treated as infinity, and no break will be allowed for such high values. Similarly, any penalty ≤ -10000 is treated as negative infinity, and a break will be forced.

```

define penalty_node = 12 { type of a penalty node }
define inf_penalty = inf_bad { “infinite” penalty value }
define eject_penalty = -inf_penalty { “negatively infinite” penalty value }
define penalty(#) ≡ mem[# + 1].int { the added cost of breaking a list here }

```

176. Anyone who has been reading the last few sections of the program will be able to guess what comes next.

```
function new_penalty(m : integer): pointer;
  var p: pointer; { the new node }
  begin p ← get_node(small_node_size); type(p) ← penalty_node; subtype(p) ← 0;
    { the subtype is not used }
  penalty(p) ← m; new_penalty ← p;
end;
```

177. You might think that we have introduced enough node types by now. Well, almost, but there is one more: An *unset_node* has nearly the same format as an *hlist_node* or *vlist_node*; it is used for entries in `\halign` or `\valign` that are not yet in their final form, since the box dimensions are their “natural” sizes before any glue adjustment has been made. The *glue_set* word is not present; instead, we have a *glue_stretch* field, which contains the total stretch of order *glue_order* that is present in the *hlist* or *vlist* being boxed. Similarly, the *shift_amount* field is replaced by a *glue_shrink* field, containing the total shrink of order *glue_sign* that is present. The *subtype* field is called *span_count*; an unset box typically contains the data for $qo(\textit{span_count}) + 1$ columns. Unset nodes will be changed to box nodes when alignment is completed.

```
define unset_node = 13 { type for an unset node }
define glue_stretch(#) ≡ mem[# + glue_offset].sc { total stretch in an unset node }
define glue_shrink ≡ shift_amount { total shrink in an unset node }
define span_count ≡ subtype { indicates the number of spanned columns }
```

178. In fact, there are still more types coming. When we get to math formula processing we will see that a *style_node* has *type* = 14; and a number of larger type codes will also be defined, for use in math mode only.

179. Warning: If any changes are made to these data structure layouts, such as changing any of the node sizes or even reordering the words of nodes, the *copy_node_list* procedure and the memory initialization code below may have to be changed. Such potentially dangerous parts of the program are listed in the index under ‘data structure assumptions’. However, other references to the nodes are made symbolically in terms of the `WEB` macro definitions above, so that format changes will leave TeX’s other algorithms intact.

180. Memory layout. Some areas of *mem* are dedicated to fixed usage, since static allocation is more efficient than dynamic allocation when we can get away with it. For example, locations *mem_bot* to *mem_bot* + 3 are always used to store the specification for glue that is ‘Opt plus Opt minus Opt’. The following macro definitions accomplish the static allocation by giving symbolic names to the fixed positions. Static variable-size nodes appear in locations *mem_bot* through *lo_mem_stat_max*, and static single-word nodes appear in locations *hi_mem_stat_min* through *mem_top*, inclusive. It is harmless to let *lig_trick* and *garbage* share the same location of *mem*.

```

define zero_glue  $\equiv$  mem_bot { specification for Opt plus Opt minus Opt }
define fil_glue  $\equiv$  zero_glue + glue_spec_size { Opt plus 1fil minus Opt }
define fill_glue  $\equiv$  fil_glue + glue_spec_size { Opt plus 1fill minus Opt }
define ss_glue  $\equiv$  fill_glue + glue_spec_size { Opt plus 1fil minus 1fil }
define fil_neg_glue  $\equiv$  ss_glue + glue_spec_size { Opt plus -1fil minus Opt }
define lo_mem_stat_max  $\equiv$  fil_neg_glue + glue_spec_size - 1
      { largest statically allocated word in the variable-size mem }

define page_ins_head  $\equiv$  mem_top { list of insertion data for current page }
define contrib_head  $\equiv$  mem_top - 1 { vlist of items not yet on current page }
define page_head  $\equiv$  mem_top - 2 { vlist for current page }
define temp_head  $\equiv$  mem_top - 3 { head of a temporary list of some kind }
define hold_head  $\equiv$  mem_top - 4 { head of a temporary list of another kind }
define adjust_head  $\equiv$  mem_top - 5 { head of adjustment list returned by hpack }
define active  $\equiv$  mem_top - 7 { head of active list in line_break, needs two words }
define align_head  $\equiv$  mem_top - 8 { head of preamble list for alignments }
define end_span  $\equiv$  mem_top - 9 { tail of spanned-width lists }
define omit_template  $\equiv$  mem_top - 10 { a constant token list }
define null_list  $\equiv$  mem_top - 11 { permanently empty list }
define lig_trick  $\equiv$  mem_top - 12 { a ligature masquerading as a char_node }
define garbage  $\equiv$  mem_top - 12 { used for scrap information }
define backup_head  $\equiv$  mem_top - 13 { head of token list built by scan_keyword }
define pre_adjust_head  $\equiv$  mem_top - 14 { head of pre-adjustment list returned by hpack }
define hi_mem_stat_min  $\equiv$  mem_top - 14 { smallest statically allocated word in the one-word mem }
define hi_mem_stat_usage = 15 { the number of one-word nodes always present }

```

181. The following code gets *mem* off to a good start, when T_EX is initializing itself the slow way.

```

⟨Local variables for initialization 19⟩ +=
k: integer; { index into mem, eqtb, etc. }

```

182. \langle Initialize table entries (done by INITEX only) 182 $\rangle \equiv$

```

for  $k \leftarrow mem\_bot + 1$  to  $lo\_mem\_stat\_max$  do  $mem[k].sc \leftarrow 0$ ; { all glue dimensions are zeroed }
 $k \leftarrow mem\_bot$ ; while  $k \leq lo\_mem\_stat\_max$  do { set first words of glue specifications }
  begin  $glue\_ref\_count(k) \leftarrow null + 1$ ;  $stretch\_order(k) \leftarrow normal$ ;  $shrink\_order(k) \leftarrow normal$ ;
   $k \leftarrow k + glue\_spec\_size$ ;
end;
 $stretch(fil\_glue) \leftarrow unity$ ;  $stretch\_order(fil\_glue) \leftarrow fil$ ;
 $stretch(fill\_glue) \leftarrow unity$ ;  $stretch\_order(fill\_glue) \leftarrow fill$ ;
 $stretch(ss\_glue) \leftarrow unity$ ;  $stretch\_order(ss\_glue) \leftarrow fil$ ;
 $shrink(ss\_glue) \leftarrow unity$ ;  $shrink\_order(ss\_glue) \leftarrow fil$ ;
 $stretch(fil\_neg\_glue) \leftarrow -unity$ ;  $stretch\_order(fil\_neg\_glue) \leftarrow fil$ ;
 $rover \leftarrow lo\_mem\_stat\_max + 1$ ;  $link(rover) \leftarrow empty\_flag$ ; { now initialize the dynamic memory }
 $node\_size(rover) \leftarrow 1000$ ; { which is a 1000-word available node }
 $llink(rover) \leftarrow rover$ ;  $rlink(rover) \leftarrow rover$ ;
 $lo\_mem\_max \leftarrow rover + 1000$ ;  $link(lo\_mem\_max) \leftarrow null$ ;  $info(lo\_mem\_max) \leftarrow null$ ;
for  $k \leftarrow hi\_mem\_stat\_min$  to  $mem\_top$  do  $mem[k] \leftarrow mem[lo\_mem\_max]$ ; { clear list heads }
 $\langle$  Initialize the special list heads and constant nodes 964  $\rangle$ ;
 $avail \leftarrow null$ ;  $mem\_end \leftarrow mem\_top$ ;  $hi\_mem\_min \leftarrow hi\_mem\_stat\_min$ ;
  { initialize the one-word memory }
 $var\_used \leftarrow lo\_mem\_stat\_max + 1 - mem\_bot$ ;  $dyn\_used \leftarrow hi\_mem\_stat\_usage$ ; { initialize statistics }

```

See also sections 240, 246, 250, 258, 268, 277, 578, 672, 1062, 1121, 1126, 1392, 1477, 1613, 1650, 1815, and 1851.

This code is used in section 8.

183. If T_EX is extended improperly, the *mem* array might get screwed up. For example, some pointers might be wrong, or some “dead” nodes might not have been freed when the last reference to them disappeared. Procedures *check_mem* and *search_mem* are available to help diagnose such problems. These procedures make use of two arrays called *free* and *was_free* that are present only if T_EX’s debugging routines have been included. (You may want to decrease the size of *mem* while you are debugging.)

\langle Global variables 13 $\rangle + \equiv$

```

debug free: packed array [ $mem\_min .. mem\_max$ ] of boolean; { free cells }
 $was\_free$ : packed array [ $mem\_min .. mem\_max$ ] of boolean; { previously free cells }
 $was\_mem\_end, was\_lo\_max, was\_hi\_min$ : pointer; { previous  $mem\_end$ ,  $lo\_mem\_max$ , and  $hi\_mem\_min$  }
 $panicking$ : boolean; { do we want to check memory constantly? }
gubed

```

184. \langle Set initial values of key variables 21 $\rangle + \equiv$

```

debug  $was\_mem\_end \leftarrow mem\_min$ ; { indicate that everything was previously free }
 $was\_lo\_max \leftarrow mem\_min$ ;  $was\_hi\_min \leftarrow mem\_max$ ;  $panicking \leftarrow false$ ;
gubed

```

185. Procedure *check_mem* makes sure that the available space lists of *mem* are well formed, and it optionally prints out all locations that are reserved now but were free the last time this procedure was called.

```

debug procedure check_mem(print_locs : boolean);
label done1, done2; { loop exits }
var p, q: pointer; { current locations of interest in mem }
    clobbered: boolean; { is something amiss? }
begin for p  $\leftarrow$  mem_min to lo_mem_max do free[p]  $\leftarrow$  false; { you can probably do this faster }
for p  $\leftarrow$  hi_mem_min to mem_end do free[p]  $\leftarrow$  false; { ditto }
 $\langle$  Check single-word avail list 186  $\rangle$ ;
 $\langle$  Check variable-size avail list 187  $\rangle$ ;
 $\langle$  Check flags of unavailable nodes 188  $\rangle$ ;
if print_locs then  $\langle$  Print newly busy locations 189  $\rangle$ ;
for p  $\leftarrow$  mem_min to lo_mem_max do was_free[p]  $\leftarrow$  free[p];
for p  $\leftarrow$  hi_mem_min to mem_end do was_free[p]  $\leftarrow$  free[p]; { was_free  $\leftarrow$  free might be faster }
was_mem_end  $\leftarrow$  mem_end; was_lo_max  $\leftarrow$  lo_mem_max; was_hi_min  $\leftarrow$  hi_mem_min;
end;
gubed

```

186. \langle Check single-word *avail* list 186 $\rangle \equiv$
p \leftarrow *avail*; *q* \leftarrow *null*; *clobbered* \leftarrow *false*;
while *p* \neq *null* **do**
begin if (*p* > *mem_end*) \vee (*p* < *hi_mem_min*) **then** *clobbered* \leftarrow *true*
else if *free*[*p*] **then** *clobbered* \leftarrow *true*;
if *clobbered* **then**
begin *print_nl*("AVAIL_list_clobbered_at_"); *print_int*(*q*); **goto** *done1*;
end;
free[*p*] \leftarrow *true*; *q* \leftarrow *p*; *p* \leftarrow *link*(*q*);
end;

done1:

This code is used in section 185.

187. \langle Check variable-size *avail* list 187 $\rangle \equiv$
p \leftarrow *rover*; *q* \leftarrow *null*; *clobbered* \leftarrow *false*;
repeat if (*p* \geq *lo_mem_max*) \vee (*p* < *mem_min*) **then** *clobbered* \leftarrow *true*
else if (*rlink*(*p*) \geq *lo_mem_max*) \vee (*rlink*(*p*) < *mem_min*) **then** *clobbered* \leftarrow *true*
else if \neg (*is_empty*(*p*)) \vee (*node_size*(*p*) < 2) \vee (*p* + *node_size*(*p*) > *lo_mem_max*) \vee
 (*llink*(*rlink*(*p*)) \neq *p*) **then** *clobbered* \leftarrow *true*;
if *clobbered* **then**
begin *print_nl*("Double-Avail_list_clobbered_at_"); *print_int*(*q*); **goto** *done2*;
end;
for *q* \leftarrow *p* **to** *p* + *node_size*(*p*) - 1 **do** { mark all locations free }
begin if *free*[*q*] **then**
begin *print_nl*("Doubly_free_location_at_"); *print_int*(*q*); **goto** *done2*;
end;
free[*q*] \leftarrow *true*;
end;
q \leftarrow *p*; *p* \leftarrow *rlink*(*p*);
until *p* = *rover*;
done2:

This code is used in section 185.

188. \langle Check flags of unavailable nodes 188 $\rangle \equiv$

```

p ← mem_min;
while p ≤ lo_mem_max do { node p should not be empty }
  begin if is_empty(p) then
    begin print_nl("Bad_flag_at_"); print_int(p);
    end;
    while (p ≤ lo_mem_max) ∧ ¬free[p] do incr(p);
    while (p ≤ lo_mem_max) ∧ free[p] do incr(p);
  end
end

```

This code is used in section 185.

189. \langle Print newly busy locations 189 $\rangle \equiv$

```

begin print_nl("New_busy_locs:");
for p ← mem_min to lo_mem_max do
  if ¬free[p] ∧ ((p > was_lo_max) ∨ was_free[p]) then
    begin print_char("_"); print_int(p);
    end;
for p ← hi_mem_min to mem_end do
  if ¬free[p] ∧ ((p < was_hi_min) ∨ (p > was_mem_end) ∨ was_free[p]) then
    begin print_char("_"); print_int(p);
    end;
end
end

```

This code is used in section 185.

190. The *search_mem* procedure attempts to answer the question “Who points to node *p*?” In doing so, it fetches *link* and *info* fields of *mem* that might not be of type *two_halves*. Strictly speaking, this is undefined in Pascal, and it can lead to “false drops” (words that seem to point to *p* purely by coincidence). But for debugging purposes, we want to rule out the places that do *not* point to *p*, so a few false drops are tolerable.

```

debug procedure search_mem(p : pointer); { look for pointers to p }
var q : integer; { current position being searched }
begin for q ← mem_min to lo_mem_max do
  begin if link(q) = p then
    begin print_nl("LINK("); print_int(q); print_char(")");
    end;
  if info(q) = p then
    begin print_nl("INFO("); print_int(q); print_char(")");
    end;
  end;
for q ← hi_mem_min to mem_end do
  begin if link(q) = p then
    begin print_nl("LINK("); print_int(q); print_char(")");
    end;
  if info(q) = p then
    begin print_nl("INFO("); print_int(q); print_char(")");
    end;
  end;
end;
 $\langle$  Search eqtb for equivalents equal to p 273  $\rangle$ ;
 $\langle$  Search save_stack for equivalents that point to p 307  $\rangle$ ;
 $\langle$  Search hyph_list for pointers to p 1108  $\rangle$ ;
end;
gubed(Declare procedures that need to be declared forward for pdfTeX 686)

```

191. Displaying boxes. We can reinforce our knowledge of the data structures just introduced by considering two procedures that display a list in symbolic form. The first of these, called *short_display*, is used in “overfull box” messages to give the top-level description of a list. The other one, called *show_node_list*, prints a detailed description of exactly what is in the data structure.

The philosophy of *short_display* is to ignore the fine points about exactly what is inside boxes, except that ligatures and discretionary breaks are expanded. As a result, *short_display* is a recursive procedure, but the recursion is never more than one level deep.

A global variable *font_in_short_display* keeps track of the font code that is assumed to be present when *short_display* begins; deviations from this font will be printed.

⟨Global variables 13⟩ +≡

font_in_short_display: integer; { an internal font number }

192. Boxes, rules, inserts, whatsits, marks, and things in general that are sort of “complicated” are indicated only by printing ‘[]’.

```

procedure print_font_identifier(f : internal_font_number);
  begin if pdf_font_blink[f] = null_font then print_esc(font_id_text(f))
  else print_esc(font_id_text(pdf_font_blink[f]))
  if pdf_tracing_fonts > 0 then
    begin print("□"); print(font_name[f]);
    if font_size[f] ≠ font_dsize[f] then
      begin print("@"); print_scaled(font_size[f]); print("pt");
      end;
    print(")");
    end
  else if pdf_font_expand_ratio[f] ≠ 0 then
    begin print("□");
    if pdf_font_expand_ratio[f] > 0 then print("+");
    print_int(pdf_font_expand_ratio[f]); print(")");
    end;
  end;
procedure short_display(p : integer); { prints highlights of list p }
  var n: integer; { for replacement counts }
  begin while p > mem_min do
    begin if is_char_node(p) then
      begin if p ≤ mem_end then
        begin if font(p) ≠ font_in_short_display then
          begin if (font(p) < font_base) ∨ (font(p) > font_max) then print_char("*")
          else print_font_identifier(font(p));
          print_char("□"); font_in_short_display ← font(p);
          end;
          print_ASCII(qo(character(p)));
          end;
        end
      else ⟨Print a short indication of the contents of node p 193⟩;
      p ← link(p);
      end;
    end;
  end;

```

193. \langle Print a short indication of the contents of node p 193 $\rangle \equiv$

```

case type( $p$ ) of
  hlist_node, vlist_node, ins_node, whatsit_node, mark_node, adjust_node, unset_node: print(" []");
  rule_node: print_char("|");
  glue_node: if glue_ptr( $p$ )  $\neq$  zero_glue then print_char("␣");
  math_node: if subtype( $p$ )  $\geq$  L_code then print(" []")
    else print_char("$");
  ligature_node: short_display(lig_ptr( $p$ ));
  disc_node: begin short_display(pre_break( $p$ )); short_display(post_break( $p$ ));
     $n \leftarrow$  replace_count( $p$ );
    while  $n > 0$  do
      begin if link( $p$ )  $\neq$  null then  $p \leftarrow$  link( $p$ );
        decr( $n$ );
      end;
    end;
  othercases do_nothing
endcases

```

This code is used in sections 192 and 674.

194. The *show_node_list* routine requires some auxiliary subroutines: one to print a font-and-character combination, one to print a token list without its reference count, and one to print a rule dimension.

```

procedure print_font_and_char( $p$  : integer); { prints char_node data }
  begin if  $p >$  mem_end then print_esc("CLOBBBERED.")
  else begin if (font( $p$ )  $<$  font_base)  $\vee$  (font( $p$ )  $>$  font_max) then print_char("*")
    else print_font_identifier(font( $p$ ));
    print_char("␣"); print_ASCII(qo(character( $p$ )));
  end;
end;

procedure print_mark( $p$  : integer); { prints token list data in braces }
  begin print_char("{");
  if ( $p <$  hi_mem_min)  $\vee$  ( $p >$  mem_end) then print_esc("CLOBBBERED.")
  else show_token_list(link( $p$ ), null, max_print_line - 10);
  print_char("}");
end;

procedure print_rule_dimen( $d$  : scaled); { prints dimension in rule node }
  begin if is_running( $d$ ) then print_char("*")
  else print_scaled( $d$ );
end;

```


195. Then there is a subroutine that prints glue stretch and shrink, possibly followed by the name of finite units:

```
procedure print_glue(d : scaled; order : integer; s : str_number); { prints a glue component }
begin print_scaled(d);
if (order < normal)  $\vee$  (order > filll) then print("foul")
else if order > normal then
  begin print("fil");
  while order > fil do
    begin print_char("l"); decr(order);
    end;
  end
else if s  $\neq$  0 then print(s);
end;
```

196. The next subroutine prints a whole glue specification.

```
procedure print_spec(p : integer; s : str_number); { prints a glue specification }
begin if (p < mem_min)  $\vee$  (p  $\geq$  lo_mem_max) then print_char("*")
else begin print_scaled(width(p));
  if s  $\neq$  0 then print(s);
  if stretch(p)  $\neq$  0 then
    begin print("_plus_"); print_glue(stretch(p), stretch_order(p), s);
    end;
  if shrink(p)  $\neq$  0 then
    begin print("_minus_"); print_glue(shrink(p), shrink_order(p), s);
    end;
  end;
end;
```

197. We also need to declare some procedures that appear later in this documentation.

⟨ Declare procedures needed for displaying the elements of mlists 865 ⟩
 ⟨ Declare the procedure called *print_skip_param* 243 ⟩

198. Since boxes can be inside of boxes, *show_node_list* is inherently recursive, up to a given maximum number of levels. The history of nesting is indicated by the current string, which will be printed at the beginning of each line; the length of this string, namely *cur_length*, is the depth of nesting.

Recursive calls on *show_node_list* therefore use the following pattern:

```
define node_list_display(#)  $\equiv$ 
  begin append_char("."); show_node_list(#); flush_char;
  end { str_room need not be checked; see show_box below }
```

199. A global variable called *depth_threshold* is used to record the maximum depth of nesting for which *show_node_list* will show information. If we have *depth_threshold* = 0, for example, only the top level information will be given and no sublists will be traversed. Another global variable, called *breadth_max*, tells the maximum number of items to show at each level; *breadth_max* had better be positive, or you won't see anything.

⟨ Global variables 13 ⟩ + \equiv

depth_threshold: *integer*; { maximum nesting depth in box displays }

breadth_max: *integer*; { maximum number of items shown at the same list level }

200. Now we are ready for *show_node_list* itself. This procedure has been written to be “extra robust” in the sense that it should not crash or get into a loop even if the data structures have been messed up by bugs in the rest of the program. You can safely call its parent routine *show_box(p)* for arbitrary values of *p* when you are debugging TEX. However, in the presence of bad data, the procedure may fetch a *memory_word* whose variant is different from the way it was stored; for example, it might try to read *mem[p].hh* when *mem[p]* contains a scaled integer, if *p* is a pointer that has been clobbered or chosen at random.

```
procedure show_node_list(p : integer); { prints a node list symbolically }
  label exit;
  var n: integer; { the number of items already printed at this level }
      g: real; { a glue ratio, as a floating point number }
  begin if cur_length > depth_threshold then
    begin if p > null then print("□[]"); { indicate that there's been some truncation }
    return;
  end;
  n ← 0;
  while p > mem_min do
    begin print_ln; print_current_string; { display the nesting history }
    if p > mem_end then { pointer out of range }
      begin print("Bad□link,□display□aborted."); return;
      end;
    incr(n);
    if n > breadth_max then { time to stop }
      begin print("etc."); return;
      end;
    ⟨ Display node p 201 ⟩;
    p ← link(p);
  end;
exit: end;
```

201. ⟨ Display node *p* 201 ⟩ ≡

```
if is_char_node(p) then print_font_and_char(p)
else case type(p) of
  hlist_node, vlist_node, unset_node: ⟨ Display box p 202 ⟩;
  rule_node: ⟨ Display rule p 205 ⟩;
  ins_node: ⟨ Display insertion p 206 ⟩;
  whatsit_node: ⟨ Display the whatsit node p 1600 ⟩;
  glue_node: ⟨ Display glue p 207 ⟩;
  margin_kern_node: begin print_esc("kern"); print_scaled(width(p));
    if subtype(p) = left_side then print("□(left□margin)")
    else print("□(right□margin)");
  end;
  kern_node: ⟨ Display kern p 209 ⟩;
  math_node: ⟨ Display math node p 210 ⟩;
  ligature_node: ⟨ Display ligature p 211 ⟩;
  penalty_node: ⟨ Display penalty p 212 ⟩;
  disc_node: ⟨ Display discretionary p 213 ⟩;
  mark_node: ⟨ Display mark p 214 ⟩;
  adjust_node: ⟨ Display adjustment p 215 ⟩;
  ⟨ Cases of show_node_list that arise in mlists only 864 ⟩
  othercases print("Unknown□node□type!")
endcases
```

This code is used in section 200.

202. $\langle \text{Display box } p \text{ 202} \rangle \equiv$

```

begin if type(p) = hlist_node then print_esc("h")
else if type(p) = vlist_node then print_esc("v")
  else print_esc("unset");
  print("box("); print_scaled(height(p)); print_char("+"); print_scaled(depth(p)); print("x");
  print_scaled(width(p));
if type(p) = unset_node then  $\langle \text{Display special fields of the unset node } p \text{ 203} \rangle$ 
else begin  $\langle \text{Display the value of } glue\_set(p) \text{ 204} \rangle$ ;
  if shift_amount(p)  $\neq 0$  then
    begin print("_shifted_"); print_scaled(shift_amount(p));
    end;
  if eTeX_ex then  $\langle \text{Display if this box is never to be reversed 1701} \rangle$ ;
  end;
  node_list_display(list_ptr(p)); { recursive call }
end

```

This code is used in section 201.

203. $\langle \text{Display special fields of the unset node } p \text{ 203} \rangle \equiv$

```

begin if span_count(p)  $\neq$  min_quarterword then
  begin print("_"); print_int(qo(span_count(p)) + 1); print("_columns");
  end;
if glue_stretch(p)  $\neq 0$  then
  begin print("_stretch_"); print_glue(glue_stretch(p), glue_order(p), 0);
  end;
if glue_shrink(p)  $\neq 0$  then
  begin print("_shrink_"); print_glue(glue_shrink(p), glue_sign(p), 0);
  end;
end

```

This code is used in section 202.

204. The code will have to change in this place if *glue_ratio* is a structured type instead of an ordinary *real*. Note that this routine should avoid arithmetic errors even if the *glue_set* field holds an arbitrary random value. The following code assumes that a properly formed nonzero *real* number has absolute value 2^{20} or more when it is regarded as an integer; this precaution was adequate to prevent floating point underflow on the author's computer.

$\langle \text{Display the value of } glue_set(p) \text{ 204} \rangle \equiv$

```

g  $\leftarrow$  float(glue_set(p));
if (g  $\neq$  float_constant(0))  $\wedge$  (glue_sign(p)  $\neq$  normal) then
  begin print("_glue_set_");
  if glue_sign(p) = shrinking then print("_");
  if abs(mem[p + glue_offset].int) < '4000000 then print("?.?")
  else if abs(g) > float_constant(20000) then
    begin if g > float_constant(0) then print_char(">")
    else print("<_");
    print_glue(20000 * unity, glue_order(p), 0);
    end
  else print_glue(round(unity * g), glue_order(p), 0);
  end

```

This code is used in section 202.

205. \langle Display rule *p* 205 $\rangle \equiv$

```
begin print_esc("rule"); print_rule_dimen(height(p)); print_char("+"); print_rule_dimen(depth(p));
print("x"); print_rule_dimen(width(p));
end
```

This code is used in section 201.

206. \langle Display insertion *p* 206 $\rangle \equiv$

```
begin print_esc("insert"); print_int(qo(subtype(p))); print(",_natural_size_");
print_scaled(height(p)); print(";_split("); print_spec(split_top_ptr(p),0); print_char(",");
print_scaled(depth(p)); print(";_float_cost_"); print_int(float_cost(p)); node_list_display(ins_ptr(p));
{ recursive call }
end
```

This code is used in section 201.

207. \langle Display glue *p* 207 $\rangle \equiv$

```
if subtype(p)  $\geq$  a_leaders then  $\langle$  Display leaders p 208  $\rangle$ 
else begin print_esc("glue");
if subtype(p)  $\neq$  normal then
begin print_char("(");
if subtype(p)  $<$  cond_math_glue then print_skip_param(subtype(p) - 1)
else if subtype(p) = cond_math_glue then print_esc("nonscript")
else print_esc("mskip");
print_char(")");
end;
if subtype(p)  $\neq$  cond_math_glue then
begin print_char("_");
if subtype(p)  $<$  cond_math_glue then print_spec(glue_ptr(p),0)
else print_spec(glue_ptr(p),"mu");
end;
end
```

This code is used in section 201.

208. \langle Display leaders *p* 208 $\rangle \equiv$

```
begin print_esc("");
if subtype(p) = c_leaders then print_char("c")
else if subtype(p) = x_leaders then print_char("x");
print("leaders_"); print_spec(glue_ptr(p),0); node_list_display(leader_ptr(p)); { recursive call }
end
```

This code is used in section 207.

209. An “explicit” kern value is indicated implicitly by an explicit space.

\langle Display kern *p* 209 $\rangle \equiv$

```
if subtype(p)  $\neq$  mu_glue then
begin print_esc("kern");
if subtype(p)  $\neq$  normal then print_char("_");
print_scaled(width(p));
if subtype(p) = acc_kern then print("_(for_accent)");
if subtype(p) = auto_kern then print("_(for_\pdfprependkern/\pdfappendkern)");
end
else begin print_esc("mkern"); print_scaled(width(p)); print("mu");
end
```

This code is used in section 201.

210. $\langle \text{Display math node } p \text{ 210} \rangle \equiv$

```

if subtype(p) > after then
  begin if end_LR(p) then print_esc("end")
  else print_esc("begin");
  if subtype(p) > R_code then print_char("R")
  else if subtype(p) > L_code then print_char("L")
    else print_char("M");
  end
else begin print_esc("math");
  if subtype(p) = before then print("on")
  else print("off");
  if width(p)  $\neq$  0 then
    begin print("_,surrounded_"); print_scaled(width(p));
    end;
  end

```

This code is used in section 201.

211. $\langle \text{Display ligature } p \text{ 211} \rangle \equiv$

```

begin print_font_and_char(lig_char(p)); print("_(ligature_");
if subtype(p) > 1 then print_char("|");
font_in_short_display  $\leftarrow$  font(lig_char(p)); short_display(lig_ptr(p));
if odd(subtype(p)) then print_char("|");
print_char("");
end

```

This code is used in section 201.

212. $\langle \text{Display penalty } p \text{ 212} \rangle \equiv$

```

begin print_esc("penalty_"); print_int(penalty(p));
end

```

This code is used in section 201.

213. The *post_break* list of a discretionary node is indicated by a prefixed ‘|’ instead of the ‘.’ before the *pre_break* list.

$\langle \text{Display discretionary } p \text{ 213} \rangle \equiv$

```

begin print_esc("discretionary");
if replace_count(p) > 0 then
  begin print("_replacing_"); print_int(replace_count(p));
  end;
node_list_display(pre_break(p)); { recursive call }
append_char("|"); show_node_list(post_break(p)); flush_char; { recursive call }
end

```

This code is used in section 201.

214. $\langle \text{Display mark } p \text{ 214} \rangle \equiv$

```

begin print_esc("mark");
if mark_class(p)  $\neq$  0 then
  begin print_char("s"); print_int(mark_class(p));
  end;
print_mark(mark_ptr(p));
end

```

This code is used in section 201.

215. \langle Display adjustment p 215 $\rangle \equiv$

```

begin print_esc("vadjust");
if adjust_pre( $p$ )  $\neq 0$  then print("_pre_");
node_list_display(adjust_ptr( $p$ )); { recursive call }
end

```

This code is used in section 201.

216. The recursive machinery is started by calling *show_box*.

```

procedure show_box( $p$  : pointer);
  begin  $\langle$  Assign the values  $depth\_threshold \leftarrow show\_box\_depth$  and  $breadth\_max \leftarrow show\_box\_breadth$  254  $\rangle$ ;
  if  $breadth\_max \leq 0$  then  $breadth\_max \leftarrow 5$ ;
  if  $pool\_ptr + depth\_threshold \geq pool\_size$  then  $depth\_threshold \leftarrow pool\_size - pool\_ptr - 1$ ;
    { now there's enough room for prefix string }
  show_node_list( $p$ ); { the show starts at  $p$  }
  print_ln;
end;

```

217. Destroying boxes. When we are done with a node list, we are obliged to return it to free storage, including all of its sublists. The recursive procedure *flush_node_list* does this for us.

218. First, however, we shall consider two non-recursive procedures that do simpler tasks. The first of these, *delete_token_ref*, is called when a pointer to a token list's reference count is being removed. This means that the token list should disappear if the reference count was *null*, otherwise the count should be decreased by one.

```

define token_ref_count(#)  $\equiv$  info(#)  { reference count preceding a token list }
procedure delete_token_ref(p : pointer);
    { p points to the reference count of a token list that is losing one reference }
    begin if token_ref_count(p) = null then flush_list(p)
    else decr(token_ref_count(p));
    end;

```

219. Similarly, *delete_glue_ref* is called when a pointer to a glue specification is being withdrawn.

```

define fast_delete_glue_ref(#)  $\equiv$ 
    begin if glue_ref_count(#) = null then free_node(#, glue_spec_size)
    else decr(glue_ref_count(#));
    end
procedure delete_glue_ref(p : pointer);  { p points to a glue specification }
    fast_delete_glue_ref(p);

```

220. Now we are ready to delete any node list, recursively. In practice, the nodes deleted are usually charnodes (about 2/3 of the time), and they are glue nodes in about half of the remaining cases.

```

procedure flush_node_list(p : pointer); { erase list of nodes starting at p }
  label done; { go here when node p has been freed }
  var q: pointer; { successor to node p }
  begin while p  $\neq$  null do
    begin q  $\leftarrow$  link(p);
    if is_char_node(p) then free_avail(p)
    else begin case type(p) of
      hlist_node, vlist_node, unset_node: begin flush_node_list(list_ptr(p)); free_node(p, box_node_size);
        goto done;
      end;
      rule_node: begin free_node(p, rule_node_size); goto done;
      end;
      ins_node: begin flush_node_list(ins_ptr(p)); delete_glue_ref(split_top_ptr(p));
        free_node(p, ins_node_size); goto done;
      end;
      whatsit_node:  $\langle$  Wipe out the whatsit node p and goto done 1602  $\rangle$ ;
      glue_node: begin fast_delete_glue_ref(glue_ptr(p));
        if leader_ptr(p)  $\neq$  null then flush_node_list(leader_ptr(p));
        end;
      kern_node, math_node, penalty_node: do_nothing;
      margin_kern_node: begin free_avail(margin_char(p)); free_node(p, margin_kern_node_size);
        goto done;
      end;
      ligature_node: flush_node_list(lig_ptr(p));
      mark_node: delete_token_ref(mark_ptr(p));
      disc_node: begin flush_node_list(pre_break(p)); flush_node_list(post_break(p));
        end;
      adjust_node: flush_node_list(adjust_ptr(p));
       $\langle$  Cases of flush_node_list that arise in mlists only 872  $\rangle$ 
      othercases confusion("flushing")
    endcases;
    free_node(p, small_node_size);
  done: end;
  p  $\leftarrow$  q;
end;
end;

```


221. Copying boxes. Another recursive operation that acts on boxes is sometimes needed: The procedure *copy_node_list* returns a pointer to another node list that has the same structure and meaning as the original. Note that since glue specifications and token lists have reference counts, we need not make copies of them. Reference counts can never get too large to fit in a halfword, since each pointer to a node is in a different memory address, and the total number of memory addresses fits in a halfword.

(Well, there actually are also references from outside *mem*; if the *save_stack* is made arbitrarily large, it would theoretically be possible to break TeX by overflowing a reference count. But who would want to do that?)

```
define add_token_ref(#)  $\equiv$  incr(token_ref_count(#)) { new reference to a token list }
define add_glue_ref(#)  $\equiv$  incr(glue_ref_count(#)) { new reference to a glue spec }
```

222. The copying procedure copies words en masse without bothering to look at their individual fields. If the node format changes—for example, if the size is altered, or if some link field is moved to another relative position—then this code may need to be changed too.

```
function copy_node_list(p : pointer): pointer;
    { makes a duplicate of the node list that starts at p and returns a pointer to the new list }
var h: pointer; { temporary head of copied list }
    q: pointer; { previous position in new list }
    r: pointer; { current node being fabricated for new list }
    words: 0 .. 5; { number of words remaining to be copied }
begin h  $\leftarrow$  get_avail; q  $\leftarrow$  h;
while p  $\neq$  null do
    begin  $\langle$  Make a copy of node p in node r 223  $\rangle$ ;
        link(q)  $\leftarrow$  r; q  $\leftarrow$  r; p  $\leftarrow$  link(p);
    end;
    link(q)  $\leftarrow$  null; q  $\leftarrow$  link(h); free_avail(h); copy_node_list  $\leftarrow$  q;
end;
```

```
223.  $\langle$  Make a copy of node p in node r 223  $\rangle \equiv$ 
    words  $\leftarrow$  1; { this setting occurs in more branches than any other }
    if is_char_node(p) then r  $\leftarrow$  get_avail
    else  $\langle$  Case statement to copy different types and set words to the number of initial words not yet
        copied 224  $\rangle$ ;
    while words > 0 do
        begin decr(words); mem[r + words]  $\leftarrow$  mem[p + words];
    end
```

This code is used in section 222.

224. \langle Case statement to copy different types and set *words* to the number of initial words not yet copied 224 $\rangle \equiv$

```

case type(p) of
  hlist_node, vlist_node, unset_node: begin r  $\leftarrow$  get_node(box_node_size); mem[r + 6]  $\leftarrow$  mem[p + 6];
    mem[r + 5]  $\leftarrow$  mem[p + 5];    { copy the last two words }
    list_ptr(r)  $\leftarrow$  copy_node_list(list_ptr(p));    { this affects mem[r + 5] }
    words  $\leftarrow$  5;
  end;
  rule_node: begin r  $\leftarrow$  get_node(rule_node_size); words  $\leftarrow$  rule_node_size;
  end;
  ins_node: begin r  $\leftarrow$  get_node(ins_node_size); mem[r + 4]  $\leftarrow$  mem[p + 4]; add_glue_ref(split_top_ptr(p));
    ins_ptr(r)  $\leftarrow$  copy_node_list(ins_ptr(p));    { this affects mem[r + 4] }
    words  $\leftarrow$  ins_node_size - 1;
  end;
  whatsit_node:  $\langle$  Make a partial copy of the whatsit node p and make r point to it; set words to the
    number of initial words not yet copied 1601  $\rangle$ ;
  glue_node: begin r  $\leftarrow$  get_node(small_node_size); add_glue_ref(glue_ptr(p)); glue_ptr(r)  $\leftarrow$  glue_ptr(p);
    leader_ptr(r)  $\leftarrow$  copy_node_list(leader_ptr(p));
  end;
  kern_node, math_node, penalty_node: begin r  $\leftarrow$  get_node(small_node_size); words  $\leftarrow$  small_node_size;
  end;
  margin_kern_node: begin r  $\leftarrow$  get_node(margin_kern_node_size); fast_get_avail(margin_char(r));
    font(margin_char(r))  $\leftarrow$  font(margin_char(p));
    character(margin_char(r))  $\leftarrow$  character(margin_char(p)); words  $\leftarrow$  small_node_size;
  end;
  ligature_node: begin r  $\leftarrow$  get_node(small_node_size); mem[lig_char(r)]  $\leftarrow$  mem[lig_char(p)];
    { copy font and character }
    lig_ptr(r)  $\leftarrow$  copy_node_list(lig_ptr(p));
  end;
  disc_node: begin r  $\leftarrow$  get_node(small_node_size); pre_break(r)  $\leftarrow$  copy_node_list(pre_break(p));
    post_break(r)  $\leftarrow$  copy_node_list(post_break(p));
  end;
  mark_node: begin r  $\leftarrow$  get_node(small_node_size); add_token_ref(mark_ptr(p));
    words  $\leftarrow$  small_node_size;
  end;
  adjust_node: begin r  $\leftarrow$  get_node(small_node_size); adjust_ptr(r)  $\leftarrow$  copy_node_list(adjust_ptr(p));
  end;    { words = 1 = small_node_size - 1 }
othercases confusion("copying")
endcases

```

This code is used in section 223.

225. The command codes. Before we can go any further, we need to define symbolic names for the internal code numbers that represent the various commands obeyed by TeX. These codes are somewhat arbitrary, but not completely so. For example, the command codes for character types are fixed by the language, since a user says, e.g., ‘`\catcode `\$ = 3`’ to make \$ a math delimiter, and the command code *math_shift* is equal to 3. Some other codes have been made adjacent so that **case** statements in the program need not consider cases that are widely spaced, or so that **case** statements can be replaced by **if** statements.

At any rate, here is the list, for future reference. First come the “catcode” commands, several of which share their numeric codes with ordinary commands when the catcode cannot emerge from TeX’s scanning routine.

```

define escape = 0   { escape delimiter (called \ in The TeXbook) }
define relax = 0   { do nothing ( \relax ) }
define left_brace = 1 { beginning of a group ( { ) }
define right_brace = 2 { ending of a group ( } ) }
define math_shift = 3 { mathematics shift character ( $ ) }
define tab_mark = 4  { alignment delimiter ( &, \span ) }
define car_ret = 5   { end of line ( carriage_return, \cr, \crcl ) }
define out_param = 5 { output a macro parameter }
define mac_param = 6 { macro parameter symbol ( # ) }
define sup_mark = 7  { superscript ( ^ ) }
define sub_mark = 8  { subscript ( _ ) }
define ignore = 9   { characters to ignore ( ^^@ ) }
define endv = 9    { end of ⟨vj⟩ list in alignment template }
define spacer = 10 { characters equivalent to blank space ( _ ) }
define letter = 11 { characters regarded as letters ( A..Z, a..z ) }
define other_char = 12 { none of the special character types }
define active_char = 13 { characters that invoke macros ( ~ ) }
define par_end = 13 { end of paragraph ( \par ) }
define match = 13  { match a macro parameter }
define comment = 14 { characters that introduce comments ( % ) }
define end_match = 14 { end of parameters to macro }
define stop = 14   { end of job ( \end, \dump ) }
define invalid_char = 15 { characters that shouldn't appear ( ^^? ) }
define delim_num = 15 { specify delimiter numerically ( \delimiter ) }
define max_char_code = 15 { largest catcode for individual characters }

```

226. Next are the ordinary run-of-the-mill command codes. Codes that are *min_internal* or more represent internal quantities that might be expanded by ‘the’.

```

define char_num = 16 {character specified numerically ( \char )}
define math_char_num = 17 {explicit math code ( \mathchar )}
define mark = 18 {mark definition ( \mark )}
define xray = 19 {peek inside of TEX ( \show, \showbox, etc. )}
define make_box = 20 {make a box ( \box, \copy, \hbox, etc. )}
define hmove = 21 {horizontal motion ( \moveleft, \moveright )}
define vmove = 22 {vertical motion ( \raise, \lower )}
define un_hbox = 23 {unglue a box ( \unhbox, \unhcopy )}
define un_vbox = 24 {unglue a box ( \unvbox, \unvcopy )}
    { ( or \pagediscards, \splitdiscards ) }
define remove_item = 25 {nullify last item ( \unpenalty, \unkern, \unskip )}
define hskip = 26 {horizontal glue ( \hskip, \hfil, etc. )}
define vskip = 27 {vertical glue ( \vskip, \vfil, etc. )}
define mskip = 28 {math glue ( \mskip )}
define kern = 29 {fixed space ( \kern )}
define mkern = 30 {math kern ( \mkern )}
define leader_ship = 31 {use a box ( \shipout, \leaders, etc. )}
define halign = 32 {horizontal table alignment ( \halign )}
define valign = 33 {vertical table alignment ( \valign )}
    { or text direction directives ( \beginL, etc. ) }
define no_align = 34 {temporary escape from alignment ( \noalign )}
define vrule = 35 {vertical rule ( \vrule )}
define hrule = 36 {horizontal rule ( \hrule )}
define insert = 37 {vlist inserted in box ( \insert )}
define vadjust = 38 {vlist inserted in enclosing paragraph ( \vadjust )}
define ignore_spaces = 39 {gobble spacer tokens ( \ignorespaces )}
define after_assignment = 40 {save till assignment is done ( \afterassignment )}
define after_group = 41 {save till group is done ( \aftergroup )}
define break_penalty = 42 {additional badness ( \penalty )}
define start_par = 43 {begin paragraph ( \indent, \noindent )}
define ital_corr = 44 {italic correction ( \ / )}
define accent = 45 {attach accent in text ( \accent )}
define math_accent = 46 {attach accent in math ( \mathaccent )}
define discretionary = 47 {discretionary texts ( \-, \discretionary )}
define eq_no = 48 {equation number ( \eqno, \leqno )}
define left_right = 49 {variable delimiter ( \left, \right )}
    { ( or \middle ) }
define math_comp = 50 {component of formula ( \mathbin, etc. )}
define limit_switch = 51 {diddle limit conventions ( \displaylimits, etc. )}
define above = 52 {generalized fraction ( \above, \atop, etc. )}
define math_style = 53 {style specification ( \displaystyle, etc. )}
define math_choice = 54 {choice specification ( \mathchoice )}
define non_script = 55 {conditional math glue ( \nonscript )}
define vcenter = 56 {vertically center a vbox ( \vcenter )}
define case_shift = 57 {force specific case ( \lowercase, \uppercase )}
define message = 58 {send to user ( \message, \errmessage )}
define extension = 59 {extensions to TEX ( \write, \special, etc. )}
define in_stream = 60 {files for reading ( \openin, \closein )}
define begin_group = 61 {begin local grouping ( \begingroup )}
define end_group = 62 {end local grouping ( \endgroup )}

```

```

define omit = 63 {omit alignment template ( \omit )}
define ex_space = 64 {explicit space ( \_ )}
define no_boundary = 65 {suppress boundary ligatures ( \noboundary )}
define radical = 66 {square root and similar signs ( \radical )}
define end_cs_name = 67 {end control sequence ( \endcsname )}
define min_internal = 68 {the smallest code that can follow \the}
define char_given = 68 {character code defined by \chardef}
define math_given = 69 {math code defined by \mathchardef}
define last_item = 70 {most recent item ( \lastpenalty, \lastkern, \lastskip )}
define max_non_prefixed_command = 70 {largest command code that can't be \global}

```

227. The next codes are special; they all relate to mode-independent assignment of values to TeX's internal registers or tables. Codes that are *max_internal* or less represent internal quantities that might be expanded by ‘\the’.

```

define toks_register = 71 {token list register ( \toks )}
define assign_toks = 72 {special token list ( \output, \everypar, etc. )}
define assign_int = 73 {user-defined integer ( \tolerance, \day, etc. )}
define assign_dimen = 74 {user-defined length ( \hsize, etc. )}
define assign_glue = 75 {user-defined glue ( \baselineskip, etc. )}
define assign_mu_glue = 76 {user-defined muglue ( \thinmuskip, etc. )}
define assign_font_dimen = 77 {user-defined font dimension ( \fontdimen )}
define assign_font_int = 78 {user-defined font integer ( \hyphenchar, \skewchar )}
define set_aux = 79 {specify state info ( \spacefactor, \prevdepth )}
define set_prev_graf = 80 {specify state info ( \prevgraf )}
define set_page_dimen = 81 {specify state info ( \pagegoal, etc. )}
define set_page_int = 82 {specify state info ( \deadcycles, \insertpenalties )}
    {( or \interactionmode )}
define set_box_dimen = 83 {change dimension of box ( \wd, \ht, \dp )}
define set_shape = 84 {specify fancy paragraph shape ( \parshape )}
    {(or \interlinepenalties, etc. )}
define def_code = 85 {define a character code ( \catcode, etc. )}
define def_family = 86 {declare math fonts ( \textfont, etc. )}
define set_font = 87 {set current font ( font identifiers )}
define def_font = 88 {define a font file ( \font )}
define register = 89 {internal register ( \count, \dimen, etc. )}
define max_internal = 89 {the largest code that can follow \the}
define advance = 90 {advance a register or parameter ( \advance )}
define multiply = 91 {multiply a register or parameter ( \multiply )}
define divide = 92 {divide a register or parameter ( \divide )}
define prefix = 93 {qualify a definition ( \global, \long, \outer )}
    {( or \protected )}
define let = 94 {assign a command code ( \let, \futurelet )}
define shorthand_def = 95 {code definition ( \chardef, \countdef, etc. )}
define read_to_cs = 96 {read into a control sequence ( \read )}
    {( or \readline )}
define def = 97 {macro definition ( \def, \gdef, \xdef, \edef )}
define set_box = 98 {set a box ( \setbox )}
define hyph_data = 99 {hyphenation data ( \hyphenation, \patterns )}
define set_interaction = 100 {define level of interaction ( \batchmode, etc. )}
define letterspace_font = 101 {letterspace a font ( \letterspacefont )}
define pdf_copy_font = 102 {create a new font instance ( \pdfcopyfont )}
define max_command = 102 {the largest command code seen at big_switch}

```

228. The remaining command codes are extra special, since they cannot get through TeX's scanner to the main control routine. They have been given values higher than *max_command* so that their special nature is easily discernible. The “expandable” commands come first.

```

define undefined_cs = max_command + 1 { initial state of most eq_type fields }
define expand_after = max_command + 2 { special expansion ( \expandafter ) }
define no_expand = max_command + 3 { special nonexpansion ( \noexpand ) }
define input = max_command + 4 { input a source file ( \input, \endinput ) }
      { ( or \scantokens ) }
define if_test = max_command + 5 { conditional text ( \if, \ifcase, etc. ) }
define fi_or_else = max_command + 6 { delimiters for conditionals ( \else, etc. ) }
define cs_name = max_command + 7 { make a control sequence from tokens ( \csname ) }
define convert = max_command + 8 { convert to text ( \number, \string, etc. ) }
define the = max_command + 9 { expand an internal quantity ( \the ) }
      { ( or \unexpanded, \detokenize ) }
define top_bot_mark = max_command + 10 { inserted mark ( \topmark, etc. ) }
define call = max_command + 11 { non-long, non-outer control sequence }
define long_call = max_command + 12 { long, non-outer control sequence }
define outer_call = max_command + 13 { non-long, outer control sequence }
define long_outer_call = max_command + 14 { long, outer control sequence }
define end_template = max_command + 15 { end of an alignment template }
define dont_expand = max_command + 16 { the following token was marked by \noexpand }
define glue_ref = max_command + 17 { the equivalent points to a glue specification }
define shape_ref = max_command + 18 { the equivalent points to a parshape specification }
define box_ref = max_command + 19 { the equivalent points to a box node, or is null }
define data = max_command + 20 { the equivalent is simply a halfword number }

```

229. The semantic nest. TeX is typically in the midst of building many lists at once. For example, when a math formula is being processed, TeX is in math mode and working on an mlist; this formula has temporarily interrupted TeX from being in horizontal mode and building the hlist of a paragraph; and this paragraph has temporarily interrupted TeX from being in vertical mode and building the vlist for the next page of a document. Similarly, when a `\vbox` occurs inside of an `\hbox`, TeX is temporarily interrupted from working in restricted horizontal mode, and it enters internal vertical mode. The “semantic nest” is a stack that keeps track of what lists and modes are currently suspended.

At each level of processing we are in one of six modes:

- vmode* stands for vertical mode (the page builder);
- hmode* stands for horizontal mode (the paragraph builder);
- mmode* stands for displayed formula mode;
- vmode* stands for internal vertical mode (e.g., in a `\vbox`);
- hmode* stands for restricted horizontal mode (e.g., in an `\hbox`);
- mmode* stands for math formula mode (not displayed).

The mode is temporarily set to zero while processing `\write` texts.

Numeric values are assigned to *vmode*, *hmode*, and *mmode* so that TeX’s “big semantic switch” can select the appropriate thing to do by computing the value $abs(mode) + cur_cmd$, where *mode* is the current mode and *cur_cmd* is the current command code.

```

define vmode = 1 { vertical mode }
define hmode = vmode + max_command + 1 { horizontal mode }
define mmode = hmode + max_command + 1 { math mode }
procedure print_mode(m : integer); { prints the mode represented by m }
begin if m > 0 then
  case m div (max_command + 1) of
    0: print("vertical");
    1: print("horizontal");
    2: print("display_math");
  end
else if m = 0 then print("no")
else case (–m) div (max_command + 1) of
  0: print("internal_vertical");
  1: print("restricted_horizontal");
  2: print("math");
end;
print("_mode");
end;

```

230. The state of affairs at any semantic level can be represented by five values:

mode is the number representing the semantic mode, as just explained.

head is a *pointer* to a list head for the list being built; *link(head)* therefore points to the first element of the list, or to *null* if the list is empty.

tail is a *pointer* to the final node of the list being built; thus, *tail* = *head* if and only if the list is empty.

prev_graf is the number of lines of the current paragraph that have already been put into the present vertical list.

aux is an auxiliary *memory_word* that gives further information that is needed to characterize the situation.

In vertical mode, *aux* is also known as *prev_depth*; it is the scaled value representing the depth of the previous box, for use in baseline calculations, or it is $\leq -1000\text{pt}$ if the next box on the vertical list is to be exempt from baseline calculations. In horizontal mode, *aux* is also known as *space_factor* and *clang*; it holds the current space factor used in spacing calculations, and the current language used for hyphenation. (The value of *clang* is undefined in restricted horizontal mode.) In math mode, *aux* is also known as *incomplete_noad*; if not *null*, it points to a record that represents the numerator of a generalized fraction for which the denominator is currently being formed in the current list.

There is also a sixth quantity, *mode_line*, which correlates the semantic nest with the user's input; *mode_line* contains the source line number at which the current level of nesting was entered. The negative of this line number is the *mode_line* at the level of the user's output routine.

A seventh quantity, *eTeX_aux*, is used by the extended features $\varepsilon\text{-TeX}$. In vertical modes it is known as *LR_save* and holds the LR stack when a paragraph is interrupted by a displayed formula. In display math mode it is known as *LR_box* and holds a pointer to a prototype box for the display. In math mode it is known as *delim_ptr* and points to the most recent *left_noad* or *middle_noad* of a *math_left_group*.

In horizontal mode, the *prev_graf* field is used for initial language data.

The semantic nest is an array called *nest* that holds the *mode*, *head*, *tail*, *prev_graf*, *aux*, and *mode_line* values for all semantic levels below the currently active one. Information about the currently active level is kept in the global quantities *mode*, *head*, *tail*, *prev_graf*, *aux*, and *mode_line*, which live in a Pascal record that is ready to be pushed onto *nest* if necessary.

define *ignore_depth* $\equiv -65536000$ { magic dimension value to mean ‘ignore me’ }

\langle Types in the outer block 18 $\rangle + \equiv$

```
list_state_record = record mode_field:  $-mmode \dots mmode$ ; head_field, tail_field: pointer;
  eTeX_aux_field: pointer;
  pg_field, ml_field: integer; aux_field: memory_word;
end;
```


231. **define** *mode* \equiv *cur_list.mode_field* { current mode }
define *head* \equiv *cur_list.head_field* { header node of current list }
define *tail* \equiv *cur_list.tail_field* { final node on current list }
define *eTeX_aux* \equiv *cur_list.eTeX_aux_field* { auxiliary data for ε -TeX }
define *LR_save* \equiv *eTeX_aux* { LR stack when a paragraph is interrupted }
define *LR_box* \equiv *eTeX_aux* { prototype box for display }
define *delim_ptr* \equiv *eTeX_aux* { most recent left or right noad of a math left group }
define *prev_graf* \equiv *cur_list.pg_field* { number of paragraph lines accumulated }
define *aux* \equiv *cur_list.aux_field* { auxiliary data about the current list }
define *prev_depth* \equiv *aux.sc* { the name of *aux* in vertical mode }
define *space_factor* \equiv *aux.hh.lh* { part of *aux* in horizontal mode }
define *clang* \equiv *aux.hh.rh* { the other part of *aux* in horizontal mode }
define *incompleteat_noad* \equiv *aux.int* { the name of *aux* in math mode }
define *mode_line* \equiv *cur_list.ml_field* { source file line number at beginning of list }

\langle Global variables 13 $\rangle + \equiv$

nest: **array** [0 .. *nest_size*] **of** *list_state_record*;
nest_ptr: 0 .. *nest_size*; { first unused location of *nest* }
max_nest_stack: 0 .. *nest_size*; { maximum of *nest_ptr* when pushing }
cur_list: *list_state_record*; { the “top” semantic state }
shown_mode: $-\text{mmode} \dots \text{mmode}$; { most recent mode shown by `\tracingcommands` }
save_tail: *pointer*; { save *tail* so we can examine whether we have an auto kern before a glue }

232. Here is a common way to make the current list grow:

```
define tail_append(#)  $\equiv$ 
  begin link(tail)  $\leftarrow$  #; tail  $\leftarrow$  link(tail);
end
```

233. We will see later that the vertical list at the bottom semantic level is split into two parts; the “current page” runs from *page_head* to *page_tail*, and the “contribution list” runs from *contrib_head* to *tail* of semantic level zero. The idea is that contributions are first formed in vertical mode, then “contributed” to the current page (during which time the page-breaking decisions are made). For now, we don’t need to know any more details about the page-building process.

\langle Set initial values of key variables 21 $\rangle + \equiv$

```
nest_ptr  $\leftarrow$  0; max_nest_stack  $\leftarrow$  0; mode  $\leftarrow$  vmode; head  $\leftarrow$  contrib_head; tail  $\leftarrow$  contrib_head;
eTeX_aux  $\leftarrow$  null; save_tail  $\leftarrow$  null; prev_depth  $\leftarrow$  ignore_depth; mode_line  $\leftarrow$  0; prev_graf  $\leftarrow$  0;
shown_mode  $\leftarrow$  0;  $\langle$ Start a new current page 1166 $\rangle$ ;
```

234. When TeX’s work on one level is interrupted, the state is saved by calling *push_nest*. This routine changes *head* and *tail* so that a new (empty) list is begun; it does not change *mode* or *aux*.

```
procedure push_nest; { enter a new semantic level, save the old }
begin if nest_ptr > max_nest_stack then
  begin max_nest_stack  $\leftarrow$  nest_ptr;
  if nest_ptr = nest_size then overflow("semantic_nest_size", nest_size);
  end;
nest[nest_ptr]  $\leftarrow$  cur_list; { stack the record }
incr(nest_ptr); head  $\leftarrow$  get_avail; tail  $\leftarrow$  head; prev_graf  $\leftarrow$  0; mode_line  $\leftarrow$  line; eTeX_aux  $\leftarrow$  null;
end;
```

235. Conversely, when T_EX is finished on the current level, the former state is restored by calling *pop_nest*. This routine will never be called at the lowest semantic level, nor will it be called unless *head* is a node that should be returned to free memory.

```
procedure pop_nest; { leave a semantic level, re-enter the old }
  begin free_avail(head); decr(nest_ptr); cur_list ← nest[nest_ptr];
  end;
```

236. Here is a procedure that displays what T_EX is working on, at all levels.

```
procedure print_totals; forward;
procedure show_activities;
  var p: 0 .. nest_size; { index into nest }
      m: -mmode .. mmode; { mode }
      a: memory_word; { auxiliary }
      q, r: pointer; { for showing the current page }
      t: integer; { ditto }
  begin nest[nest_ptr] ← cur_list; { put the top level into the array }
  print_nl(""); print_ln;
  for p ← nest_ptr downto 0 do
    begin m ← nest[p].mode_field; a ← nest[p].aux_field; print_nl("###"); print_mode(m);
    print("_entered_at_line_"); print_int(abs(nest[p].ml_field));
    if m = hmode then
      if nest[p].pg_field ≠ '40600000 then
        begin print("_(language"); print_int(nest[p].pg_field mod '200000); print(":hyphenmin");
        print_int(nest[p].pg_field div '20000000); print_char("");
        print_int((nest[p].pg_field div '200000) mod '100); print_char("");
        end;
      if nest[p].ml_field < 0 then print("_(\output_routine)");
    if p = 0 then
      begin ⟨ Show the status of the current page 1161 ⟩;
      if link(contrib_head) ≠ null then print_nl("###_recent_contributions:");
      end;
    show_box(link(nest[p].head_field)); ⟨ Show the auxiliary field, a 237 ⟩;
  end;
end;
```

237. $\langle \text{Show the auxiliary field, } a \text{ 237} \rangle \equiv$
case $abs(m)$ **div** $(max_command + 1)$ **of**
0: **begin** $print_nl("prevdepth_");$
 if $a.sc \leq pdf_ignored_dimen$ **then** $print("ignored")$
 else $print_scaled(a.sc);$
 if $nest[p].pg_field \neq 0$ **then**
 begin $print(",_prevgraf_"); print_int(nest[p].pg_field); print("_line");$
 if $nest[p].pg_field \neq 1$ **then** $print_char("s");$
 end;
 end;
1: **begin** $print_nl("spacefactor_"); print_int(a.hh.lh);$
 if $m > 0$ **then if** $a.hh.rh > 0$ **then**
 begin $print(",_current_language_"); print_int(a.hh.rh);$ **end;**
 end;
2: **if** $a.int \neq null$ **then**
 begin $print("this_will_begin_denominator_of:"); show_box(a.int);$ **end;**
end { there are no other cases }

This code is used in section 236.

238. The table of equivalents. Now that we have studied the data structures for T_EX’s semantic routines, we ought to consider the data structures used by its syntactic routines. In other words, our next concern will be the tables that T_EX looks at when it is scanning what the user has written.

The biggest and most important such table is called *eqtb*. It holds the current “equivalents” of things; i.e., it explains what things mean or what their current values are, for all quantities that are subject to the nesting structure provided by T_EX’s grouping mechanism. There are six parts to *eqtb*:

- 1) *eqtb*[*active_base* .. (*hash_base* − 1)] holds the current equivalents of single-character control sequences.
- 2) *eqtb*[*hash_base* .. (*glue_base* − 1)] holds the current equivalents of multiletter control sequences.
- 3) *eqtb*[*glue_base* .. (*local_base* − 1)] holds the current equivalents of glue parameters like the current *baselineskip*.
- 4) *eqtb*[*local_base* .. (*int_base* − 1)] holds the current equivalents of local halfword quantities like the current box registers, the current “catcodes,” the current font, and a pointer to the current paragraph shape.
- 5) *eqtb*[*int_base* .. (*dimen_base* − 1)] holds the current equivalents of fullword integer parameters like the current hyphenation penalty.
- 6) *eqtb*[*dimen_base* .. *eqtb_size*] holds the current equivalents of fullword dimension parameters like the current *hsize* or amount of hanging indentation.

Note that, for example, the current amount of *baselineskip* glue is determined by the setting of a particular location in region 3 of *eqtb*, while the current meaning of the control sequence ‘\baselineskip’ (which might have been changed by \def or \let) appears in region 2.

239. Each entry in *eqtb* is a *memory_word*. Most of these words are of type *two_halves*, and subdivided into three fields:

- 1) The *eq_level* (a quarterword) is the level of grouping at which this equivalent was defined. If the level is *level_zero*, the equivalent has never been defined; *level_one* refers to the outer level (outside of all groups), and this level is also used for global definitions that never go away. Higher levels are for equivalents that will disappear at the end of their group.
- 2) The *eq_type* (another quarterword) specifies what kind of entry this is. There are many types, since each T_EX primitive like \hbox, \def, etc., has its own special code. The list of command codes above includes all possible settings of the *eq_type* field.
- 3) The *equiv* (a halfword) is the current equivalent value. This may be a font number, a pointer into *mem*, or a variety of other things.

```
define eq_level_field(#) ≡ #.hh.b1
```

```
define eq_type_field(#) ≡ #.hh.b0
```

```
define equiv_field(#) ≡ #.hh.rh
```

```
define eq_level(#) ≡ eq_level_field(eqtb[#]) { level of definition }
```

```
define eq_type(#) ≡ eq_type_field(eqtb[#]) { command code for equivalent }
```

```
define equiv(#) ≡ equiv_field(eqtb[#]) { equivalent value }
```

```
define level_zero = min_quarterword { level for undefined quantities }
```

```
define level_one = level_zero + 1 { outermost level for defined quantities }
```

240. Many locations in *eqtb* have symbolic names. The purpose of the next paragraphs is to define these names, and to set up the initial values of the equivalents.

In the first region we have 256 equivalents for “active characters” that act as control sequences, followed by 256 equivalents for single-character control sequences.

Then comes region 2, which corresponds to the hash table that we will define later. The maximum address in this region is used for a dummy control sequence that is perpetually undefined. There also are several locations for control sequences that are perpetually defined (since they are used in error recovery).

```

define active_base = 1    { beginning of region 1, for active character equivalents }
define single_base = active_base + 256 { equivalents of one-character control sequences }
define null_cs = single_base + 256 { equivalent of \csname\endcsname }
define hash_base = null_cs + 1    { beginning of region 2, for the hash table }
define frozen_control_sequence = hash_base + hash_size { for error recovery }
define frozen_protection = frozen_control_sequence { inaccessible but definable }
define frozen_cr = frozen_control_sequence + 1 { permanent ‘\cr’ }
define frozen_end_group = frozen_control_sequence + 2 { permanent ‘\endgroup’ }
define frozen_right = frozen_control_sequence + 3 { permanent ‘\right’ }
define frozen_fi = frozen_control_sequence + 4 { permanent ‘\fi’ }
define frozen_end_template = frozen_control_sequence + 5 { permanent ‘\endtemplate’ }
define frozen_endv = frozen_control_sequence + 6 { second permanent ‘\endtemplate’ }
define frozen_relax = frozen_control_sequence + 7 { permanent ‘\relax’ }
define end_write = frozen_control_sequence + 8 { permanent ‘\endwrite’ }
define frozen_dont_expand = frozen_control_sequence + 9 { permanent ‘\notexpanded:’ }
define prim_size = 2100 { maximum number of primitives }
define frozen_null_font = frozen_control_sequence + 10 { permanent ‘\nullfont’ }
define frozen_primitive = frozen_control_sequence + 11 { permanent ‘\pdfprimitive’ }
define prim_eqtb_base = frozen_primitive + 1
define font_id_base = frozen_null_font - font_base { begins table of 257 permanent font identifiers }
define undefined_control_sequence = frozen_null_font + 257 { dummy location }
define glue_base = undefined_control_sequence + 1 { beginning of region 3 }

```

⟨ Initialize table entries (done by INITEX only) 182 ⟩ +≡

```

eq_type(undefined_control_sequence) ← undefined_cs; equiv(undefined_control_sequence) ← null;
eq_level(undefined_control_sequence) ← level_zero;
for k ← active_base to undefined_control_sequence - 1 do eqtb[k] ← eqtb[undefined_control_sequence];

```

241. Here is a routine that displays the current meaning of an *eqtb* entry in region 1 or 2. (Similar routines for the other regions will appear below.)

⟨ Show equivalent *n*, in region 1 or 2 241 ⟩ ≡

```

begin sprint_cs(n); print_char("="); print_cmd_chr(eq_type(n), equiv(n));
if eq_type(n) ≥ call then
  begin print_char(":"); show_token_list(link(equiv(n)), null, 32);
  end;
end

```

This code is used in section 270.

242. Region 3 of *eqtb* contains the 256 `\skip` registers, as well as the glue parameters defined here. It is important that the “muskip” parameters have larger numbers than the others.

```

define line_skip_code = 0 { interline glue if baseline_skip is infeasible }
define baseline_skip_code = 1 { desired glue between baselines }
define par_skip_code = 2 { extra glue just above a paragraph }
define above_display_skip_code = 3 { extra glue just above displayed math }
define below_display_skip_code = 4 { extra glue just below displayed math }
define above_display_short_skip_code = 5 { glue above displayed math following short lines }
define below_display_short_skip_code = 6 { glue below displayed math following short lines }
define left_skip_code = 7 { glue at left of justified lines }
define right_skip_code = 8 { glue at right of justified lines }
define top_skip_code = 9 { glue at top of main pages }
define split_top_skip_code = 10 { glue at top of split pages }
define tab_skip_code = 11 { glue between aligned entries }
define space_skip_code = 12 { glue between words (if not zero_glue) }
define xspace_skip_code = 13 { glue after sentences (if not zero_glue) }
define par_fill_skip_code = 14 { glue on last line of paragraph }
define thin_mu_skip_code = 15 { thin space in math formula }
define med_mu_skip_code = 16 { medium space in math formula }
define thick_mu_skip_code = 17 { thick space in math formula }
define glue_pars = 18 { total number of glue parameters }
define skip_base = glue_base + glue_pars { table of 256 “skip” registers }
define mu_skip_base = skip_base + 256 { table of 256 “muskip” registers }
define local_base = mu_skip_base + 256 { beginning of region 4 }

define skip(#) $\equiv$ equiv(skip_base + #) { mem location of glue specification }
define mu_skip(#) $\equiv$ equiv(mu_skip_base + #) { mem location of math glue spec }
define glue_par(#) $\equiv$ equiv(glue_base + #) { mem location of glue specification }
define line_skip  $\equiv$  glue_par(line_skip_code)
define baseline_skip  $\equiv$  glue_par(baseline_skip_code)
define par_skip  $\equiv$  glue_par(par_skip_code)
define above_display_skip  $\equiv$  glue_par(above_display_skip_code)
define below_display_skip  $\equiv$  glue_par(below_display_skip_code)
define above_display_short_skip  $\equiv$  glue_par(above_display_short_skip_code)
define below_display_short_skip  $\equiv$  glue_par(below_display_short_skip_code)
define left_skip  $\equiv$  glue_par(left_skip_code)
define right_skip  $\equiv$  glue_par(right_skip_code)
define top_skip  $\equiv$  glue_par(top_skip_code)
define split_top_skip  $\equiv$  glue_par(split_top_skip_code)
define tab_skip  $\equiv$  glue_par(tab_skip_code)
define space_skip  $\equiv$  glue_par(space_skip_code)
define xspace_skip  $\equiv$  glue_par(xspace_skip_code)
define par_fill_skip  $\equiv$  glue_par(par_fill_skip_code)
define thin_mu_skip  $\equiv$  glue_par(thin_mu_skip_code)
define med_mu_skip  $\equiv$  glue_par(med_mu_skip_code)
define thick_mu_skip  $\equiv$  glue_par(thick_mu_skip_code)

```

(Current *mem* equivalent of glue parameter number *n* 242) \equiv *glue_par*(*n*)

This code is used in sections 170 and 172.

243. Sometimes we need to convert TeX's internal code numbers into symbolic form. The *print_skip_param* routine gives the symbolic name of a glue parameter.

⟨ Declare the procedure called *print_skip_param* 243 ⟩ \equiv

```
procedure print_skip_param(n : integer);
  begin case n of
    line_skip_code: print_esc("lineskip");
    baseline_skip_code: print_esc("baselineskip");
    par_skip_code: print_esc("parskip");
    above_display_skip_code: print_esc("abovedisplayskip");
    below_display_skip_code: print_esc("belowdisplayskip");
    above_display_short_skip_code: print_esc("abovedisplayshortskip");
    below_display_short_skip_code: print_esc("belowdisplayshortskip");
    left_skip_code: print_esc("leftskip");
    right_skip_code: print_esc("rightskip");
    top_skip_code: print_esc("topskip");
    split_top_skip_code: print_esc("splittopskip");
    tab_skip_code: print_esc("tabskip");
    space_skip_code: print_esc("spaceskip");
    xspace_skip_code: print_esc("xspaceskip");
    par_fill_skip_code: print_esc("parfillskip");
    thin_mu_skip_code: print_esc("thinmuskip");
    med_mu_skip_code: print_esc("medmuskip");
    thick_mu_skip_code: print_esc("thickmuskip");
    othercases print("[unknown_glue_parameter!]")
  endcases;
end;
```

This code is used in section 197.

244. The symbolic names for glue parameters are put into TeX's hash table by using the routine called *primitive*, defined below. Let us enter them now, so that we don't have to list all those parameter names anywhere else.

```

⟨ Put each of TeX's primitives into the hash table 244 ⟩ ≡
  primitive("lineskip", assign_glue, glue_base + line_skip_code);
  primitive("baselineskip", assign_glue, glue_base + baseline_skip_code);
  primitive("parskip", assign_glue, glue_base + par_skip_code);
  primitive("abovedisplayskip", assign_glue, glue_base + above_display_skip_code);
  primitive("belowdisplayskip", assign_glue, glue_base + below_display_skip_code);
  primitive("abovedisplayshortskip", assign_glue, glue_base + above_display_short_skip_code);
  primitive("belowdisplayshortskip", assign_glue, glue_base + below_display_short_skip_code);
  primitive("leftskip", assign_glue, glue_base + left_skip_code);
  primitive("rightskip", assign_glue, glue_base + right_skip_code);
  primitive("topskip", assign_glue, glue_base + top_skip_code);
  primitive("splittopskip", assign_glue, glue_base + split_top_skip_code);
  primitive("tabskip", assign_glue, glue_base + tab_skip_code);
  primitive("spaceskip", assign_glue, glue_base + space_skip_code);
  primitive("xspaceskip", assign_glue, glue_base + xspace_skip_code);
  primitive("parfillskip", assign_glue, glue_base + par_fill_skip_code);
  primitive("thinmuskip", assign_mu_glue, glue_base + thin_mu_skip_code);
  primitive("medmuskip", assign_mu_glue, glue_base + med_mu_skip_code);
  primitive("thickmuskip", assign_mu_glue, glue_base + thick_mu_skip_code);

```

See also sections 248, 256, 266, 287, 356, 402, 410, 437, 442, 494, 513, 517, 579, 954, 1158, 1228, 1234, 1247, 1264, 1283, 1290, 1317, 1332, 1345, 1354, 1364, 1384, 1395, 1398, 1406, 1426, 1430, 1438, 1448, 1453, 1462, 1467, and 1522.

This code is used in section 1514.

```

245. ⟨ Cases of print_cmd_chr for symbolic printing of primitives 245 ⟩ ≡
  assign_glue, assign_mu_glue: if chr_code < skip_base then print_skip_param(chr_code - glue_base)
  else if chr_code < mu_skip_base then
    begin print_esc("skip"); print_int(chr_code - skip_base);
    end
  else begin print_esc("muskip"); print_int(chr_code - mu_skip_base);
  end;

```

See also sections 249, 257, 267, 288, 357, 403, 411, 438, 443, 495, 514, 518, 955, 1159, 1229, 1235, 1248, 1265, 1284, 1291, 1319, 1333, 1346, 1355, 1365, 1385, 1396, 1399, 1407, 1427, 1431, 1437, 1439, 1449, 1454, 1463, 1468, 1471, and 1524.

This code is used in section 320.

246. All glue parameters and registers are initially '0pt plus0pt minus0pt'.

```

⟨ Initialize table entries (done by INITEX only) 182 ⟩ +≡
  equiv(glue_base) ← zero_glue; eq_level(glue_base) ← level_one; eq_type(glue_base) ← glue_ref;
  for k ← glue_base + 1 to local_base - 1 do eqtb[k] ← eqtb[glue_base];
  glue_ref_count(zero_glue) ← glue_ref_count(zero_glue) + local_base - glue_base;

```


247. ⟨Show equivalent n , in region 3 247⟩ \equiv

```

if  $n < skip\_base$  then
  begin  $print\_skip\_param(n - glue\_base)$ ;  $print\_char(=)$ ;
  if  $n < glue\_base + thin\_mu\_skip\_code$  then  $print\_spec(equiv(n), \text{"pt"})$ 
  else  $print\_spec(equiv(n), \text{"mu"})$ ;
  end
else if  $n < mu\_skip\_base$  then
  begin  $print\_esc(\text{"skip"})$ ;  $print\_int(n - skip\_base)$ ;  $print\_char(=)$ ;  $print\_spec(equiv(n), \text{"pt"})$ ;
  end
  else begin  $print\_esc(\text{"muskip"})$ ;  $print\_int(n - mu\_skip\_base)$ ;  $print\_char(=)$ ;
     $print\_spec(equiv(n), \text{"mu"})$ ;
  end

```

This code is used in section 270.

248. Region 4 of *eqtb* contains the local quantities defined here. The bulk of this region is taken up by five tables that are indexed by eight-bit characters; these tables are important to both the syntactic and semantic portions of TeX. There are also a bunch of special things like font and token parameters, as well as the tables of `\toks` and `\box` registers.

```

define par_shape_loc = local_base { specifies paragraph shape }
define output_routine_loc = local_base + 1 { points to token list for \output }
define every_par_loc = local_base + 2 { points to token list for \everypar }
define every_math_loc = local_base + 3 { points to token list for \everymath }
define every_display_loc = local_base + 4 { points to token list for \everydisplay }
define every_hbox_loc = local_base + 5 { points to token list for \everyhbox }
define every_vbox_loc = local_base + 6 { points to token list for \everyvbox }
define every_job_loc = local_base + 7 { points to token list for \everyjob }
define every_cr_loc = local_base + 8 { points to token list for \everycr }
define err_help_loc = local_base + 9 { points to token list for \errhelp }
define tex_toks = local_base + 10 { end of TeX's token list parameters }

define pdfTeX_first_loc = tex_toks { base for pdfTeX's token list parameters }
define pdf_pages_attr_loc = pdfTeX_first_loc + 0 { points to token list for \pdfpagesattr }
define pdf_page_attr_loc = pdfTeX_first_loc + 1 { points to token list for \pdfpageattr }
define pdf_page_resources_loc = pdfTeX_first_loc + 2 { points to token list for \pdfpageresources }
define pdf_pk_mode_loc = pdfTeX_first_loc + 3 { points to token list for \pdfpkmode }
define pdf_toks = pdfTeX_first_loc + 4 { end of pdfTeX's token list parameters }

define etex_toks_base = pdf_toks { base for  $\epsilon$ -TeX's token list parameters }
define every_eof_loc = etex_toks_base { points to token list for \everyeof }
define etex_toks = etex_toks_base + 1 { end of  $\epsilon$ -TeX's token list parameters }

define toks_base = etex_toks { table of 256 token list registers }

define etex_pen_base = toks_base + 256 { start of table of  $\epsilon$ -TeX's penalties }
define inter_line_penalties_loc = etex_pen_base { additional penalties between lines }
define club_penalties_loc = etex_pen_base + 1 { penalties for creating club lines }
define widow_penalties_loc = etex_pen_base + 2 { penalties for creating widow lines }
define display_widow_penalties_loc = etex_pen_base + 3 { ditto, just before a display }
define etex_pens = etex_pen_base + 4 { end of table of  $\epsilon$ -TeX's penalties }

define box_base = etex_pens { table of 256 box registers }
define cur_font_loc = box_base + 256 { internal font number outside math mode }
define math_font_base = cur_font_loc + 1 { table of 48 math font numbers }
define cat_code_base = math_font_base + 48 { table of 256 command codes (the "catcodes") }
define lc_code_base = cat_code_base + 256 { table of 256 lowercase mappings }
define uc_code_base = lc_code_base + 256 { table of 256 uppercase mappings }
define sf_code_base = uc_code_base + 256 { table of 256 spacefactor mappings }
define math_code_base = sf_code_base + 256 { table of 256 math mode mappings }
define int_base = math_code_base + 256 { beginning of region 5 }

define par_shape_ptr  $\equiv$  equiv(par_shape_loc)
define output_routine  $\equiv$  equiv(output_routine_loc)
define every_par  $\equiv$  equiv(every_par_loc)
define every_math  $\equiv$  equiv(every_math_loc)
define every_display  $\equiv$  equiv(every_display_loc)
define every_hbox  $\equiv$  equiv(every_hbox_loc)
define every_vbox  $\equiv$  equiv(every_vbox_loc)
define every_job  $\equiv$  equiv(every_job_loc)
define every_cr  $\equiv$  equiv(every_cr_loc)
define err_help  $\equiv$  equiv(err_help_loc)
define pdf_pages_attr  $\equiv$  equiv(pdf_pages_attr_loc)

```

```

define pdf_page_attr  $\equiv$  equiv(pdf_page_attr_loc)
define pdf_page_resources  $\equiv$  equiv(pdf_page_resources_loc)
define pdf_pk_mode  $\equiv$  equiv(pdf_pk_mode_loc)
define toks( $\#$ )  $\equiv$  equiv(toks_base +  $\#$ )
define box( $\#$ )  $\equiv$  equiv(box_base +  $\#$ )
define cur_font  $\equiv$  equiv(cur_font_loc)
define fam_fnt( $\#$ )  $\equiv$  equiv(math_font_base +  $\#$ )
define cat_code( $\#$ )  $\equiv$  equiv(cat_code_base +  $\#$ )
define lc_code( $\#$ )  $\equiv$  equiv(lc_code_base +  $\#$ )
define uc_code( $\#$ )  $\equiv$  equiv(uc_code_base +  $\#$ )
define sf_code( $\#$ )  $\equiv$  equiv(sf_code_base +  $\#$ )
define math_code( $\#$ )  $\equiv$  equiv(math_code_base +  $\#$ )
      { Note: math_code(c) is the true math code plus min_halfword }

```

⟨ Put each of TeX's primitives into the hash table 244 ⟩ \equiv

```

primitive("output", assign_toks, output_routine_loc); primitive("everypar", assign_toks, every_par_loc);
primitive("everymath", assign_toks, every_math_loc);
primitive("everydisplay", assign_toks, every_display_loc);
primitive("everyhbox", assign_toks, every_hbox_loc); primitive("everyvbox", assign_toks, every_vbox_loc);
primitive("everyjob", assign_toks, every_job_loc); primitive("everycr", assign_toks, every_cr_loc);
primitive("errhelp", assign_toks, err_help_loc);
primitive("pdfpagesattr", assign_toks, pdf_pages_attr_loc);
primitive("pdfpageattr", assign_toks, pdf_page_attr_loc);
primitive("pdfpageresources", assign_toks, pdf_page_resources_loc);
primitive("pdfpkmode", assign_toks, pdf_pk_mode_loc);

```

249. ⟨ Cases of *print_cmd_chr* for symbolic printing of primitives 245 ⟩ \equiv

```

assign_toks: if chr_code  $\geq$  toks_base then
  begin print_esc("toks"); print_int(chr_code - toks_base);
  end
else case chr_code of
  output_routine_loc: print_esc("output");
  every_par_loc: print_esc("everypar");
  every_math_loc: print_esc("everymath");
  every_display_loc: print_esc("everydisplay");
  every_hbox_loc: print_esc("everyhbox");
  every_vbox_loc: print_esc("everyvbox");
  every_job_loc: print_esc("everyjob");
  every_cr_loc: print_esc("everycr");
  ⟨ Cases of assign_toks for print_cmd_chr 1655 ⟩
  pdf_pages_attr_loc: print_esc("pdfpagesattr");
  pdf_page_attr_loc: print_esc("pdfpageattr");
  pdf_page_resources_loc: print_esc("pdfpageresources");
  pdf_pk_mode_loc: print_esc("pdfpkmode");
  othercases print_esc("errhelp")
endcases;

```

250. We initialize most things to null or undefined values. An undefined font is represented by the internal code *font_base*.

However, the character code tables are given initial values based on the conventional interpretation of ASCII code. These initial values should not be changed when T_EX is adapted for use with non-English languages; all changes to the initialization conventions should be made in format packages, not in T_EX itself, so that global interchange of formats is possible.

```

define  null_font  $\equiv$  font_base
define  var_code  $\equiv$  '70000 { math code meaning "use the current family" }

⟨ Initialize table entries (done by INITEX only) 182 ⟩ +≡
par_shape_ptr  $\leftarrow$  null; eq_type(par_shape_loc)  $\leftarrow$  shape_ref; eq_level(par_shape_loc)  $\leftarrow$  level_one;
for k  $\leftarrow$  etex_pen_base to etex_pens - 1 do eqtb[k]  $\leftarrow$  eqtb[par_shape_loc];
for k  $\leftarrow$  output_routine_loc to toks_base + 255 do eqtb[k]  $\leftarrow$  eqtb[undefined_control_sequence];
box(0)  $\leftarrow$  null; eq_type(box_base)  $\leftarrow$  box_ref; eq_level(box_base)  $\leftarrow$  level_one;
for k  $\leftarrow$  box_base + 1 to box_base + 255 do eqtb[k]  $\leftarrow$  eqtb[box_base];
cur_font  $\leftarrow$  null_font; eq_type(cur_font_loc)  $\leftarrow$  data; eq_level(cur_font_loc)  $\leftarrow$  level_one;
for k  $\leftarrow$  math_font_base to math_font_base + 47 do eqtb[k]  $\leftarrow$  eqtb[cur_font_loc];
equiv(cat_code_base)  $\leftarrow$  0; eq_type(cat_code_base)  $\leftarrow$  data; eq_level(cat_code_base)  $\leftarrow$  level_one;
for k  $\leftarrow$  cat_code_base + 1 to int_base - 1 do eqtb[k]  $\leftarrow$  eqtb[cat_code_base];
for k  $\leftarrow$  0 to 255 do
  begin cat_code(k)  $\leftarrow$  other_char; math_code(k)  $\leftarrow$  hi(k); sf_code(k)  $\leftarrow$  1000;
  end;
cat_code(carriage_return)  $\leftarrow$  car_ret; cat_code("␣")  $\leftarrow$  spacer; cat_code("\\")  $\leftarrow$  escape;
cat_code("%")  $\leftarrow$  comment; cat_code(invalid_code)  $\leftarrow$  invalid_char; cat_code(null_code)  $\leftarrow$  ignore;
for k  $\leftarrow$  "0" to "9" do math_code(k)  $\leftarrow$  hi(k + var_code);
for k  $\leftarrow$  "A" to "Z" do
  begin cat_code(k)  $\leftarrow$  letter; cat_code(k + "a" - "A")  $\leftarrow$  letter;
  math_code(k)  $\leftarrow$  hi(k + var_code + "100");
  math_code(k + "a" - "A")  $\leftarrow$  hi(k + "a" - "A" + var_code + "100");
  lc_code(k)  $\leftarrow$  k + "a" - "A"; lc_code(k + "a" - "A")  $\leftarrow$  k + "a" - "A";
  uc_code(k)  $\leftarrow$  k; uc_code(k + "a" - "A")  $\leftarrow$  k;
  sf_code(k)  $\leftarrow$  999;
  end;

```

251. $\langle \text{Show equivalent } n, \text{ in region 4 } \textcolor{blue}{251} \rangle \equiv$

```

if ( $n = \text{par\_shape\_loc}$ )  $\vee ((n \geq \text{etex\_pen\_base}) \wedge (n < \text{etex\_pens}))$  then
  begin  $\text{print\_cmd\_chr}(\text{set\_shape}, n)$ ;  $\text{print\_char}("=")$ ;
  if  $\text{equiv}(n) = \text{null}$  then  $\text{print\_char}("0")$ 
  else if  $n > \text{par\_shape\_loc}$  then
    begin  $\text{print\_int}(\text{penalty}(\text{equiv}(n)))$ ;  $\text{print\_char}("\square")$ ;  $\text{print\_int}(\text{penalty}(\text{equiv}(n) + 1))$ ;
    if  $\text{penalty}(\text{equiv}(n)) > 1$  then  $\text{print\_esc}(\text{"ETC."})$ ;
    end
     $\text{print\_int}(\text{info}(\text{par\_shape\_ptr}))$ ;
  end
else if  $n < \text{toks\_base}$  then
  begin  $\text{print\_cmd\_chr}(\text{assign\_toks}, n)$ ;  $\text{print\_char}("=")$ ;
  if  $\text{equiv}(n) \neq \text{null}$  then  $\text{show\_token\_list}(\text{link}(\text{equiv}(n)), \text{null}, 32)$ ;
  end
else if  $n < \text{box\_base}$  then
  begin  $\text{print\_esc}(\text{"toks"})$ ;  $\text{print\_int}(n - \text{toks\_base})$ ;  $\text{print\_char}("=")$ ;
  if  $\text{equiv}(n) \neq \text{null}$  then  $\text{show\_token\_list}(\text{link}(\text{equiv}(n)), \text{null}, 32)$ ;
  end
else if  $n < \text{cur\_font\_loc}$  then
  begin  $\text{print\_esc}(\text{"box"})$ ;  $\text{print\_int}(n - \text{box\_base})$ ;  $\text{print\_char}("=")$ ;
  if  $\text{equiv}(n) = \text{null}$  then  $\text{print}(\text{"void"})$ 
  else begin  $\text{depth\_threshold} \leftarrow 0$ ;  $\text{breadth\_max} \leftarrow 1$ ;  $\text{show\_node\_list}(\text{equiv}(n))$ ;
  end;
  end
  else if  $n < \text{cat\_code\_base}$  then  $\langle \text{Show the font identifier in } \text{eqtb}[n] \textcolor{blue}{252} \rangle$ 
  else  $\langle \text{Show the halfword code in } \text{eqtb}[n] \textcolor{blue}{253} \rangle$ 

```

This code is used in section [270](#).

252. $\langle \text{Show the font identifier in } \text{eqtb}[n] \textcolor{blue}{252} \rangle \equiv$

```

begin if  $n = \text{cur\_font\_loc}$  then  $\text{print}(\text{"current\_font"})$ 
else if  $n < \text{math\_font\_base} + 16$  then
  begin  $\text{print\_esc}(\text{"textfont"})$ ;  $\text{print\_int}(n - \text{math\_font\_base})$ ;
  end
else if  $n < \text{math\_font\_base} + 32$  then
  begin  $\text{print\_esc}(\text{"scriptfont"})$ ;  $\text{print\_int}(n - \text{math\_font\_base} - 16)$ ;
  end
  else begin  $\text{print\_esc}(\text{"scriptscriptfont"})$ ;  $\text{print\_int}(n - \text{math\_font\_base} - 32)$ ;
  end;
 $\text{print\_char}("=")$ ;
 $\text{print\_esc}(\text{hash}[\text{font\_id\_base} + \text{equiv}(n)].\text{rh})$ ; { that's  $\text{font\_id\_text}(\text{equiv}(n))$  }
end

```

This code is used in section [251](#).

253. \langle Show the halfword code in *eqtb*[*n*] 253 $\rangle \equiv$

```

if n < math_code_base then
  begin if n < lc_code_base then
    begin print_esc("catcode"); print_int(n − cat_code_base);
    end
  else if n < uc_code_base then
    begin print_esc("lccode"); print_int(n − lc_code_base);
    end
  else if n < sf_code_base then
    begin print_esc("uccode"); print_int(n − uc_code_base);
    end
    begin print_esc("sfcode"); print_int(n − sf_code_base);
    end;
  print_char("="); print_int(equiv(n));
  end
else begin print_esc("mathcode"); print_int(n − math_code_base); print_char("=");
  print_int(ho(equiv(n)));
  end

```

This code is used in section 251.

254. Region 5 of *eqtb* contains the integer parameters and registers defined here, as well as the *del_code* table. The latter table differs from the *cat_code* .. *math_code* tables that precede it, since delimiter codes are fullword integers while the other kinds of codes occupy at most a halfword. This is what makes region 5 different from region 4. We will store the *eq_level* information in an auxiliary array of quarterwords that will be defined later.

```

define pretolerance_code = 0 {badness tolerance before hyphenation}
define tolerance_code = 1 {badness tolerance after hyphenation}
define line_penalty_code = 2 {added to the badness of every line}
define hyphen_penalty_code = 3 {penalty for break after discretionary hyphen}
define ex_hyphen_penalty_code = 4 {penalty for break after explicit hyphen}
define club_penalty_code = 5 {penalty for creating a club line}
define widow_penalty_code = 6 {penalty for creating a widow line}
define display_widow_penalty_code = 7 {ditto, just before a display}
define broken_penalty_code = 8 {penalty for breaking a page at a broken line}
define bin_op_penalty_code = 9 {penalty for breaking after a binary operation}
define rel_penalty_code = 10 {penalty for breaking after a relation}
define pre_display_penalty_code = 11 {penalty for breaking just before a displayed formula}
define post_display_penalty_code = 12 {penalty for breaking just after a displayed formula}
define inter_line_penalty_code = 13 {additional penalty between lines}
define double_hyphen_demerits_code = 14 {demerits for double hyphen break}
define final_hyphen_demerits_code = 15 {demerits for final hyphen break}
define adj_demerits_code = 16 {demerits for adjacent incompatible lines}
define mag_code = 17 {magnification ratio}
define delimiter_factor_code = 18 {ratio for variable-size delimiters}
define looseness_code = 19 {change in number of lines for a paragraph}
define time_code = 20 {current time of day}
define day_code = 21 {current day of the month}
define month_code = 22 {current month of the year}
define year_code = 23 {current year of our Lord}
define show_box_breadth_code = 24 {nodes per level in show_box}
define show_box_depth_code = 25 {maximum level in show_box}
define hbadness_code = 26 {hboxes exceeding this badness will be shown by hpack}
define vbadness_code = 27 {vboxes exceeding this badness will be shown by vpack}
define pausing_code = 28 {pause after each line is read from a file}
define tracing_online_code = 29 {show diagnostic output on terminal}
define tracing_macros_code = 30 {show macros as they are being expanded}
define tracing_stats_code = 31 {show memory usage if TeX knows it}
define tracing_paragraphs_code = 32 {show line-break calculations}
define tracing_pages_code = 33 {show page-break calculations}
define tracing_output_code = 34 {show boxes when they are shipped out}
define tracing_lost_chars_code = 35 {show characters that aren't in the font}
define tracing_commands_code = 36 {show command codes at big_switch}
define tracing_restores_code = 37 {show equivalents when they are restored}
define uc_hyph_code = 38 {hyphenate words beginning with a capital letter}
define output_penalty_code = 39 {penalty found at current page break}
define max_dead_cycles_code = 40 {bound on consecutive dead cycles of output}
define hang_after_code = 41 {hanging indentation changes after this many lines}
define floating_penalty_code = 42 {penalty for insertions held over after a split}
define global_defs_code = 43 {override \global specifications}
define cur_fam_code = 44 {current family}
define escape_char_code = 45 {escape character for token output}
define default_hyphen_char_code = 46 {value of \hyphenchar when a font is loaded}

```

```

define default_skew_char_code = 47 { value of \skewchar when a font is loaded }
define end_line_char_code = 48 { character placed at the right end of the buffer }
define new_line_char_code = 49 { character that prints as print\n }
define language_code = 50 { current hyphenation table }
define left_hyphen_min_code = 51 { minimum left hyphenation fragment size }
define right_hyphen_min_code = 52 { minimum right hyphenation fragment size }
define holding_inserts_code = 53 { do not remove insertion nodes from \box255 }
define error_context_lines_code = 54 { maximum intermediate line pairs shown }
define tex_int_pars = 55 { total number of TeX's integer parameters }

define pdftex_first_integer_code = tex_int_pars { base for pdfTeX's integer parameters }
define pdf_output_code = pdftex_first_integer_code + 0 { switch on PDF output if positive }
define pdf_compress_level_code = pdftex_first_integer_code + 1 { compress level of streams }
define pdf_decimal_digits_code = pdftex_first_integer_code + 2
    { digits after the decimal point of numbers }
define pdf_move_chars_code = pdftex_first_integer_code + 3 { move chars 0..31 to higher area if possible }
define pdf_image_resolution_code = pdftex_first_integer_code + 4 { default image resolution }
define pdf_pk_resolution_code = pdftex_first_integer_code + 5 { default resolution of PK font }
define pdf_unique_resname_code = pdftex_first_integer_code + 6 { generate unique names for resources }
define pdf_option_always_use_pdfpagebox_code = pdftex_first_integer_code + 7
    { if the PDF inclusion should always use a specific PDF page box }
define pdf_option_pdf_inclusion_errorlevel_code = pdftex_first_integer_code + 8
    { if the PDF inclusion should treat pdfs newer than pdf_minor_version as an error }
define pdf_major_version_code = pdftex_first_integer_code + 9
    { integer part of the PDF version produced }
define pdf_minor_version_code = pdftex_first_integer_code + 10
    { fractional part of the PDF version produced }
define pdf_force_pagebox_code = pdftex_first_integer_code + 11
    { if the PDF inclusion should always use a specific PDF page box }
define pdf_pagebox_code = pdftex_first_integer_code + 12 { default pagebox to use for PDF inclusion }
define pdf_inclusion_errorlevel_code = pdftex_first_integer_code + 13
    { if the PDF inclusion should treat pdfs newer than pdf_minor_version as an error }
define pdf_gamma_code = pdftex_first_integer_code + 14
define pdf_image_gamma_code = pdftex_first_integer_code + 15
define pdf_image_hicolor_code = pdftex_first_integer_code + 16
define pdf_image_apply_gamma_code = pdftex_first_integer_code + 17
define pdf_adjust_spacing_code = pdftex_first_integer_code + 18 { level of spacing adjusting }
define pdf_protrude_chars_code = pdftex_first_integer_code + 19
    { protrude chars at left/right edge of paragraphs }
define pdf_tracing_fonts_code = pdftex_first_integer_code + 20 { level of font detail in log }
define pdf_objcompresslevel_code = pdftex_first_integer_code + 21 { activate object streams }
define pdf_adjust_interword_glue_code = pdftex_first_integer_code + 22 { adjust interword glue? }
define pdf_prepend_kern_code = pdftex_first_integer_code + 23
    { prepend kern before certain characters? }
define pdf_append_kern_code = pdftex_first_integer_code + 24 { append kern before certain characters? }
define pdf_gen_tounicode_code = pdftex_first_integer_code + 25 { generate ToUnicode for fonts? }
define pdf_draftmode_code = pdftex_first_integer_code + 26 { switch on draftmode if positive }
define pdf_inclusion_copy_font_code = pdftex_first_integer_code + 27 { generate ToUnicode for fonts? }
define pdf_suppress_warning_dup_dest_code = pdftex_first_integer_code + 28
    { suppress warning about duplicated destinations }
define pdf_suppress_warning_dup_map_code = pdftex_first_integer_code + 29
    { suppress warning about duplicated map lines }
define pdf_suppress_warning_page_group_code = pdftex_first_integer_code + 30

```



```

    { suppress warning about multiple pdfs with page group }
define pdf_info_omit_date_code = pdftex_first_integer_code + 31
    { omit generating CreationDate and ModDate }
define pdf_suppress_ptex_info_code = pdftex_first_integer_code + 32
    { suppress /PTEX.* entries in PDF dictionaries }
define pdf_omit_charset_code = pdftex_first_integer_code + 33
    { suppress /PTEX.* entries in PDF dictionaries }
define pdf_int_pars = pdftex_first_integer_code + 34 { total number of pdfTeX's integer parameters }
define etex_int_base = pdf_int_pars { base for  $\varepsilon$ -TeX's integer parameters }
define tracing_assigns_code = etex_int_base { show assignments }
define tracing_groups_code = etex_int_base + 1 { show save/restore groups }
define tracing_ifs_code = etex_int_base + 2 { show conditionals }
define tracing_scan_tokens_code = etex_int_base + 3 { show pseudo file open and close }
define tracing_nesting_code = etex_int_base + 4 { show incomplete groups and ifs within files }
define pre_display_direction_code = etex_int_base + 5 { text direction preceding a display }
define last_line_fit_code = etex_int_base + 6 { adjustment for last line of paragraph }
define saving_vdiscards_code = etex_int_base + 7 { save items discarded from vlists }
define saving_hyph_codes_code = etex_int_base + 8 { save hyphenation codes for languages }
define eTeX_state_code = etex_int_base + 9 {  $\varepsilon$ -TeX state variables }
define etex_int_pars = eTeX_state_code + eTeX_states { total number of  $\varepsilon$ -TeX's integer parameters }
define int_pars = etex_int_pars { total number of integer parameters }
define count_base = int_base + int_pars { 256 user \count registers }
define del_code_base = count_base + 256 { 256 delimiter code mappings }
define dimen_base = del_code_base + 256 { beginning of region 6 }
define del_code(#)  $\equiv$  eqtb[del_code_base + #].int
define count(#)  $\equiv$  eqtb[count_base + #].int
define int_par(#)  $\equiv$  eqtb[int_base + #].int { an integer parameter }
define pretolerance  $\equiv$  int_par(pretolerance_code)
define tolerance  $\equiv$  int_par(tolerance_code)
define line_penalty  $\equiv$  int_par(line_penalty_code)
define hyphen_penalty  $\equiv$  int_par(hyphen_penalty_code)
define ex_hyphen_penalty  $\equiv$  int_par(ex_hyphen_penalty_code)
define club_penalty  $\equiv$  int_par(club_penalty_code)
define widow_penalty  $\equiv$  int_par(widow_penalty_code)
define display_widow_penalty  $\equiv$  int_par(display_widow_penalty_code)
define broken_penalty  $\equiv$  int_par(broken_penalty_code)
define bin_op_penalty  $\equiv$  int_par(bin_op_penalty_code)
define rel_penalty  $\equiv$  int_par(rel_penalty_code)
define pre_display_penalty  $\equiv$  int_par(pre_display_penalty_code)
define post_display_penalty  $\equiv$  int_par(post_display_penalty_code)
define inter_line_penalty  $\equiv$  int_par(inter_line_penalty_code)
define double_hyphen_demerits  $\equiv$  int_par(double_hyphen_demerits_code)
define final_hyphen_demerits  $\equiv$  int_par(final_hyphen_demerits_code)
define adj_demerits  $\equiv$  int_par(adj_demerits_code)
define mag  $\equiv$  int_par(mag_code)
define delimiter_factor  $\equiv$  int_par(delimiter_factor_code)
define looseness  $\equiv$  int_par(looseness_code)
define time  $\equiv$  int_par(time_code)
define day  $\equiv$  int_par(day_code)
define month  $\equiv$  int_par(month_code)
define year  $\equiv$  int_par(year_code)
define show_box_breadth  $\equiv$  int_par(show_box_breadth_code)

```

```

define show_box_depth  $\equiv$  int_par(show_box_depth_code)
define hbadness  $\equiv$  int_par(hbadness_code)
define vbadness  $\equiv$  int_par(vbadness_code)
define pausing  $\equiv$  int_par(pausing_code)
define tracing_online  $\equiv$  int_par(tracing_online_code)
define tracing_macros  $\equiv$  int_par(tracing_macros_code)
define tracing_stats  $\equiv$  int_par(tracing_stats_code)
define tracing_paragraphs  $\equiv$  int_par(tracing_paragraphs_code)
define tracing_pages  $\equiv$  int_par(tracing_pages_code)
define tracing_output  $\equiv$  int_par(tracing_output_code)
define tracing_lost_chars  $\equiv$  int_par(tracing_lost_chars_code)
define tracing_commands  $\equiv$  int_par(tracing_commands_code)
define tracing_restores  $\equiv$  int_par(tracing_restores_code)
define uc_hyph  $\equiv$  int_par(uc_hyph_code)
define output_penalty  $\equiv$  int_par(output_penalty_code)
define max_dead_cycles  $\equiv$  int_par(max_dead_cycles_code)
define hang_after  $\equiv$  int_par(hang_after_code)
define floating_penalty  $\equiv$  int_par(floating_penalty_code)
define global_defs  $\equiv$  int_par(global_defs_code)
define cur_fam  $\equiv$  int_par(cur_fam_code)
define escape_char  $\equiv$  int_par(escape_char_code)
define default_hyphen_char  $\equiv$  int_par(default_hyphen_char_code)
define default_skew_char  $\equiv$  int_par(default_skew_char_code)
define end_line_char  $\equiv$  int_par(end_line_char_code)
define new_line_char  $\equiv$  int_par(new_line_char_code)
define language  $\equiv$  int_par(language_code)
define left_hyphen_min  $\equiv$  int_par(left_hyphen_min_code)
define right_hyphen_min  $\equiv$  int_par(right_hyphen_min_code)
define holding_inserts  $\equiv$  int_par(holding_inserts_code)
define error_context_lines  $\equiv$  int_par(error_context_lines_code)

define pdf_adjust_spacing  $\equiv$  int_par(pdf_adjust_spacing_code)
define pdf_protrude_chars  $\equiv$  int_par(pdf_protrude_chars_code)
define pdf_tracing_fonts  $\equiv$  int_par(pdf_tracing_fonts_code)
define pdf_adjust_interword_glue  $\equiv$  int_par(pdf_adjust_interword_glue_code)
define pdf_prepend_kern  $\equiv$  int_par(pdf_prepend_kern_code)
define pdf_append_kern  $\equiv$  int_par(pdf_append_kern_code)
define pdf_gen_tounicode  $\equiv$  int_par(pdf_gen_tounicode_code)
define pdf_output  $\equiv$  int_par(pdf_output_code)
define pdf_compress_level  $\equiv$  int_par(pdf_compress_level_code)
define pdf_objcompresslevel  $\equiv$  int_par(pdf_objcompresslevel_code)
define pdf_decimal_digits  $\equiv$  int_par(pdf_decimal_digits_code)
define pdf_move_chars  $\equiv$  int_par(pdf_move_chars_code)
define pdf_image_resolution  $\equiv$  int_par(pdf_image_resolution_code)
define pdf_pk_resolution  $\equiv$  int_par(pdf_pk_resolution_code)
define pdf_unique_resname  $\equiv$  int_par(pdf_unique_resname_code)
define pdf_option_always_use_pdfpagebox  $\equiv$  int_par(pdf_option_always_use_pdfpagebox_code)
define pdf_option_pdf_inclusion_errorlevel  $\equiv$  int_par(pdf_option_pdf_inclusion_errorlevel_code)
define pdf_major_version  $\equiv$  int_par(pdf_major_version_code)
define pdf_minor_version  $\equiv$  int_par(pdf_minor_version_code)
define pdf_force_pagebox  $\equiv$  int_par(pdf_force_pagebox_code)
define pdf_pagebox  $\equiv$  int_par(pdf_pagebox_code)
define pdf_inclusion_errorlevel  $\equiv$  int_par(pdf_inclusion_errorlevel_code)

```

```

define pdf_gamma ≡ int_par(pdf_gamma_code)
define pdf_image_gamma ≡ int_par(pdf_image_gamma_code)
define pdf_image_hicolor ≡ int_par(pdf_image_hicolor_code)
define pdf_image_apply_gamma ≡ int_par(pdf_image_apply_gamma_code)
define pdf_draftmode ≡ int_par(pdf_draftmode_code)
define pdf_inclusion_copy_font ≡ int_par(pdf_inclusion_copy_font_code)
define pdf_suppress_warning_dup_dest ≡ int_par(pdf_suppress_warning_dup_dest_code)
define pdf_suppress_warning_dup_map ≡ int_par(pdf_suppress_warning_dup_map_code)
define pdf_suppress_warning_page_group ≡ int_par(pdf_suppress_warning_page_group_code)
define pdf_info_omit_date ≡ int_par(pdf_info_omit_date_code)
define pdf_suppress_ptex_info ≡ int_par(pdf_suppress_ptex_info_code)
define pdf_omit_charset ≡ int_par(pdf_omit_charset_code)

define tracing_assigns ≡ int_par(tracing_assigns_code)
define tracing_groups ≡ int_par(tracing_groups_code)
define tracing_ifs ≡ int_par(tracing_ifs_code)
define tracing_scan_tokens ≡ int_par(tracing_scan_tokens_code)
define tracing_nesting ≡ int_par(tracing_nesting_code)
define pre_display_direction ≡ int_par(pre_display_direction_code)
define last_line_fit ≡ int_par(last_line_fit_code)
define saving_vdiscards ≡ int_par(saving_vdiscards_code)
define saving_hyph_codes ≡ int_par(saving_hyph_codes_code)

⟨ Assign the values depth_threshold ← show_box_depth and breadth_max ← show_box_breadth 254 ⟩ ≡
  depth_threshold ← show_box_depth; breadth_max ← show_box_breadth

```

This code is used in section 216.

255. We can print the symbolic name of an integer parameter as follows.

```

procedure print_param(n : integer);
begin case n of
  pretolerance_code: print_esc("pretolerance");
  tolerance_code: print_esc("tolerance");
  line_penalty_code: print_esc("linepenalty");
  hyphen_penalty_code: print_esc("hyphenpenalty");
  ex_hyphen_penalty_code: print_esc("exhyphenpenalty");
  club_penalty_code: print_esc("clubpenalty");
  widow_penalty_code: print_esc("widowpenalty");
  display_widow_penalty_code: print_esc("displaywidowpenalty");
  broken_penalty_code: print_esc("brokenpenalty");
  bin_op_penalty_code: print_esc("binoppenalty");
  rel_penalty_code: print_esc("relpenalty");
  pre_display_penalty_code: print_esc("predisplaypenalty");
  post_display_penalty_code: print_esc("postdisplaypenalty");
  inter_line_penalty_code: print_esc("interlinepenalty");
  double_hyphen_demerits_code: print_esc("doublehyphendemerits");
  final_hyphen_demerits_code: print_esc("finalhyphendemerits");
  adj_demerits_code: print_esc("adjdemerits");
  mag_code: print_esc("mag");
  delimiter_factor_code: print_esc("delimiterfactor");
  looseness_code: print_esc("looseness");
  time_code: print_esc("time");
  day_code: print_esc("day");
  month_code: print_esc("month");
  year_code: print_esc("year");
  show_box_breadth_code: print_esc("showboxbreadth");
  show_box_depth_code: print_esc("showboxdepth");
  hbadness_code: print_esc("hbadness");
  vbadness_code: print_esc("vbadness");
  pausing_code: print_esc("pausing");
  tracing_online_code: print_esc("tracingonline");
  tracing_macros_code: print_esc("tracingmacros");
  tracing_stats_code: print_esc("tracingstats");
  tracing_paragraphs_code: print_esc("tracingparagraphs");
  tracing_pages_code: print_esc("tracingpages");
  tracing_output_code: print_esc("tracingoutput");
  tracing_lost_chars_code: print_esc("tracinglostchars");
  tracing_commands_code: print_esc("tracingcommands");
  tracing_restores_code: print_esc("tracingrestores");
  uc_hyph_code: print_esc("uchyph");
  output_penalty_code: print_esc("outputpenalty");
  max_dead_cycles_code: print_esc("maxdeadcycles");
  hang_after_code: print_esc("hangafter");
  floating_penalty_code: print_esc("floatingpenalty");
  global_defs_code: print_esc("globaldefs");
  cur_fam_code: print_esc("fam");
  escape_char_code: print_esc("escapechar");
  default_hyphen_char_code: print_esc("defaultthyphenchar");
  default_skew_char_code: print_esc("defaultskewchar");
  end_line_char_code: print_esc("endlinechar");

```

```

new_line_char_code: print_esc("newlinechar");
language_code: print_esc("language");
left_hyphen_min_code: print_esc("lefthyphenmin");
right_hyphen_min_code: print_esc("righthyphenmin");
holding_inserts_code: print_esc("holdinginserts");
error_context_lines_code: print_esc("errorcontextlines");

pdf_output_code: print_esc("pdfoutput");
pdf_compress_level_code: print_esc("pdfcompresslevel");
pdf_objcompresslevel_code: print_esc("pdfobjcompresslevel");
pdf_decimal_digits_code: print_esc("pdfdecimaldigits");
pdf_move_chars_code: print_esc("pdfmovechars");
pdf_image_resolution_code: print_esc("pdfimageresolution");
pdf_pk_resolution_code: print_esc("pdfpkresolution");
pdf_unique_resname_code: print_esc("pdfuniqueresname");
pdf_option_always_use_pdfpagebox_code: print_esc("pdfoptionalwaysusepdfpagebox");
pdf_option_pdf_inclusion_errorlevel_code: print_esc("pdfoptionpdfinclusionerrorlevel");
pdf_major_version_code: print_esc("pdfmajorversion");
pdf_minor_version_code: print_esc("pdfminorversion");
pdf_force_pagebox_code: print_esc("pdfforcepagebox");
pdf_pagebox_code: print_esc("pdfpagebox");
pdf_inclusion_errorlevel_code: print_esc("pdfinclusionerrorlevel");
pdf_gamma_code: print_esc("pdfgamma");
pdf_image_gamma_code: print_esc("pdfimagegamma");
pdf_image_hicolor_code: print_esc("pdfimagehicolor");
pdf_image_apply_gamma_code: print_esc("pdfimageapplygamma");
pdf_adjust_spacing_code: print_esc("pdfadjustspacing");
pdf_protrude_chars_code: print_esc("pdfprotrudechars");
pdf_tracing_fonts_code: print_esc("pdftracingfonts");
pdf_adjust_interword_glue_code: print_esc("pdfadjustinterwordglue");
pdf_prepend_kern_code: print_esc("pdfprependkern");
pdf_append_kern_code: print_esc("pdfappendkern");
pdf_gen_tounicode_code: print_esc("pdfgentounicode");
pdf_draftmode_code: print_esc("pdfdraftmode");
pdf_inclusion_copy_font_code: print_esc("pdfinclusioncopyfonts");
pdf_suppress_warning_dup_dest_code: print_esc("pdfsuppresswarningdupdest");
pdf_suppress_warning_dup_map_code: print_esc("pdfsuppresswarningdupmap");
pdf_suppress_warning_page_group_code: print_esc("pdfsuppresswarningpagegroup");
pdf_info_omit_date_code: print_esc("pdfinfoomitdate");
pdf_suppress_ptex_info_code: print_esc("pdfsuppressptexinfo");
pdf_omit_charset_code: print_esc("pdfomitcharset");
  { Cases for print_param 1656 }
othercases print("[unknown_integer_parameter!"]
endcases;
end;
```

256. The integer parameter names must be entered into the hash table.

(Put each of TeX's primitives into the hash table 244) +≡

```
primitive("pretolerance", assign_int, int_base + pretolerance_code);
primitive("tolerance", assign_int, int_base + tolerance_code);
primitive("linepenalty", assign_int, int_base + line_penalty_code);
primitive("hyphenpenalty", assign_int, int_base + hyphen_penalty_code);
primitive("exhyphenpenalty", assign_int, int_base + ex_hyphen_penalty_code);
primitive("clubpenalty", assign_int, int_base + club_penalty_code);
primitive("widowpenalty", assign_int, int_base + widow_penalty_code);
primitive("displaywidowpenalty", assign_int, int_base + display_widow_penalty_code);
primitive("brokenpenalty", assign_int, int_base + broken_penalty_code);
primitive("binoppenalty", assign_int, int_base + bin_op_penalty_code);
primitive("relpenalty", assign_int, int_base + rel_penalty_code);
primitive("predisdisplaypenalty", assign_int, int_base + pre_display_penalty_code);
primitive("postdisplaypenalty", assign_int, int_base + post_display_penalty_code);
primitive("interlinepenalty", assign_int, int_base + inter_line_penalty_code);
primitive("doublehyphendemerits", assign_int, int_base + double_hyphen_demerits_code);
primitive("finalhyphendemerits", assign_int, int_base + final_hyphen_demerits_code);
primitive("adjdemerits", assign_int, int_base + adj_demerits_code);
primitive("mag", assign_int, int_base + mag_code);
primitive("delimiterfactor", assign_int, int_base + delimiter_factor_code);
primitive("looseness", assign_int, int_base + looseness_code);
primitive("time", assign_int, int_base + time_code);
primitive("day", assign_int, int_base + day_code);
primitive("month", assign_int, int_base + month_code);
primitive("year", assign_int, int_base + year_code);
primitive("showboxbreadth", assign_int, int_base + show_box_breadth_code);
primitive("showboxdepth", assign_int, int_base + show_box_depth_code);
primitive("hbadness", assign_int, int_base + hbadness_code);
primitive("vbadness", assign_int, int_base + vbadness_code);
primitive("pausing", assign_int, int_base + pausing_code);
primitive("tracingonline", assign_int, int_base + tracing_online_code);
primitive("tracingmacros", assign_int, int_base + tracing_macros_code);
primitive("tracingstats", assign_int, int_base + tracing_stats_code);
primitive("tracingparagraphs", assign_int, int_base + tracing_paragraphs_code);
primitive("tracingpages", assign_int, int_base + tracing_pages_code);
primitive("tracingoutput", assign_int, int_base + tracing_output_code);
primitive("tracinglostchars", assign_int, int_base + tracing_lost_chars_code);
primitive("tracingcommands", assign_int, int_base + tracing_commands_code);
primitive("tracingrestores", assign_int, int_base + tracing_restores_code);
primitive("uchyph", assign_int, int_base + uc_hyph_code);
primitive("outputpenalty", assign_int, int_base + output_penalty_code);
primitive("maxdeadcycles", assign_int, int_base + max_dead_cycles_code);
primitive("hangafter", assign_int, int_base + hang_after_code);
primitive("floatingpenalty", assign_int, int_base + floating_penalty_code);
primitive("globaldefs", assign_int, int_base + global_defs_code);
primitive("fam", assign_int, int_base + cur_fam_code);
primitive("escapechar", assign_int, int_base + escape_char_code);
primitive("defaultthyphenchar", assign_int, int_base + default_hyphen_char_code);
primitive("defaultskewchar", assign_int, int_base + default_skew_char_code);
primitive("endlinechar", assign_int, int_base + end_line_char_code);
primitive("newlinechar", assign_int, int_base + new_line_char_code);
```

```

primitive("language", assign_int, int_base + language_code);
primitive("lefthyphenmin", assign_int, int_base + left_hyphen_min_code);
primitive("righthyphenmin", assign_int, int_base + right_hyphen_min_code);
primitive("holdinginserts", assign_int, int_base + holding_inserts_code);
primitive("errorcontextlines", assign_int, int_base + error_context_lines_code);
primitive("pdfoutput", assign_int, int_base + pdf_output_code);
primitive("pdfcompresslevel", assign_int, int_base + pdf_compress_level_code);
primitive("pdfobjcompresslevel", assign_int, int_base + pdf_objcompresslevel_code);
primitive("pdfdecimaldigits", assign_int, int_base + pdf_decimal_digits_code);
primitive("pdfmovechars", assign_int, int_base + pdf_move_chars_code);
primitive("pdfimageresolution", assign_int, int_base + pdf_image_resolution_code);
primitive("pdfpkresolution", assign_int, int_base + pdf_pk_resolution_code);
primitive("pdfuniqueresname", assign_int, int_base + pdf_unique_resname_code);
primitive("pdfoptionpdfminorversion", assign_int, int_base + pdf_minor_version_code);
primitive("pdfoptionalwaysusepdfpagebox", assign_int,
    int_base + pdf_option_always_use_pdfpagebox_code);
primitive("pdfoptionpdfinclusionerrorlevel", assign_int,
    int_base + pdf_option_pdf_inclusion_errorlevel_code);
primitive("pdfmajorversion", assign_int, int_base + pdf_major_version_code);
primitive("pdfminorversion", assign_int, int_base + pdf_minor_version_code);
primitive("pdfforcepagebox", assign_int, int_base + pdf_force_pagebox_code);
primitive("pdfpagebox", assign_int, int_base + pdf_pagebox_code);
primitive("pdfinclusionerrorlevel", assign_int, int_base + pdf_inclusion_errorlevel_code);
primitive("pdfgamma", assign_int, int_base + pdf_gamma_code);
primitive("pdfimagegamma", assign_int, int_base + pdf_image_gamma_code);
primitive("pdfimagehicolor", assign_int, int_base + pdf_image_hicolor_code);
primitive("pdfimageapplygamma", assign_int, int_base + pdf_image_apply_gamma_code);
primitive("pdfadjustspacing", assign_int, int_base + pdf_adjust_spacing_code);
primitive("pdfprotrudechars", assign_int, int_base + pdf_protrude_chars_code);
primitive("pdftracingfonts", assign_int, int_base + pdf_tracing_fonts_code);
primitive("pdfadjustinterwordglue", assign_int, int_base + pdf_adjust_interword_glue_code);
primitive("pdfprependkern", assign_int, int_base + pdf_prepend_kern_code);
primitive("pdfappendkern", assign_int, int_base + pdf_append_kern_code);
primitive("pdfgentounicode", assign_int, int_base + pdf_gen_tounicode_code);
primitive("pdfdraftmode", assign_int, int_base + pdf_draftmode_code);
primitive("pdfinclusioncopyfonts", assign_int, int_base + pdf_inclusion_copy_font_code);
primitive("pdfsuppresswarningdupdest", assign_int, int_base + pdf_suppress_warning_dup_dest_code);
primitive("pdfsuppresswarningdupmap", assign_int, int_base + pdf_suppress_warning_dup_map_code);
primitive("pdfsuppresswarningpagegroup", assign_int, int_base + pdf_suppress_warning_page_group_code);
primitive("pdfinfoomitdate", assign_int, int_base + pdf_info_omit_date_code);
primitive("pdfsuppressptexinfo", assign_int, int_base + pdf_suppress_ptex_info_code);
primitive("pdfomitcharset", assign_int, int_base + pdf_omit_charset_code);

```

257. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
assign_int: if *chr_code* < *count_base* then *print_param*(*chr_code* − *int_base*)
 else begin *print_esc*("count"); *print_int*(*chr_code* − *count_base*);
 end;

258. The integer parameters should really be initialized by a macro package; the following initialization does the minimum to keep T_EX from complete failure.

```

⟨Initialize table entries (done by INITEX only) 182⟩ +≡
  for k ← int_base to del_code_base − 1 do eqtb[k].int ← 0;
  mag ← 1000; tolerance ← 10000; hang_after ← 1; max_dead_cycles ← 25; escape_char ← "\";
  end_line_char ← carriage_return;
  for k ← 0 to 255 do del_code(k) ← −1;
  del_code(".") ← 0; { this null delimiter is used in error recovery }

```

259. The following procedure, which is called just before T_EX initializes its input and output, establishes the initial values of the date and time. Since standard Pascal cannot provide such information, something special is needed. The program here simply assumes that suitable values appear in the global variables *sys_time*, *sys_day*, *sys_month*, and *sys_year* (which are initialized to noon on 4 July 1776, in case the implementor is careless).

```

procedure fix_date_and_time;
  begin sys_time ← 12 * 60; sys_day ← 4; sys_month ← 7; sys_year ← 1776; { self-evident truths }
  time ← sys_time; { minutes since midnight }
  day ← sys_day; { day of the month }
  month ← sys_month; { month of the year }
  year ← sys_year; { Anno Domini }
end;

```

```

260. ⟨Show equivalent n, in region 5 260⟩ ≡
  begin if n < count_base then print_param(n − int_base)
  else if n < del_code_base then
    begin print_esc("count"); print_int(n − count_base);
    end
    else begin print_esc("delcode"); print_int(n − del_code_base);
    end;
  print_char("="); print_int(eqtb[n].int);
end

```

This code is used in section 270.

```

261. ⟨Set variable c to the current escape character 261⟩ ≡
  c ← escape_char

```

This code is used in section 63.

```

262. ⟨Character s is the current new-line character 262⟩ ≡
  s = new_line_char

```

This code is used in sections 58 and 59.

263. TeX is occasionally supposed to print diagnostic information that goes only into the transcript file, unless *tracing_online* is positive. Here are two routines that adjust the destination of print commands:

```
procedure begin_diagnostic; { prepare to do some tracing }
  begin old_setting  $\leftarrow$  selector;
  if (tracing_online  $\leq$  0)  $\wedge$  (selector = term_and_log) then
    begin decr(selector);
    if history = spotless then history  $\leftarrow$  warning_issued;
    end;
  end;

procedure end_diagnostic(blank_line : boolean); { restore proper conditions after tracing }
  begin print_nl("");
  if blank_line then print_ln;
  selector  $\leftarrow$  old_setting;
  end;
```

264. Of course we had better declare a few more global variables, if the previous routines are going to work.

\langle Global variables 13 $\rangle + \equiv$

old_setting: 0 .. *max_selector*;

sys_time, *sys_day*, *sys_month*, *sys_year*: *integer*; { date and time supplied by external system }

265. The final region of *eqtb* contains the dimension parameters defined here, and the 256 `\dimen` registers.

```

define par_indent_code = 0 { indentation of paragraphs }
define math_surround_code = 1 { space around math in text }
define line_skip_limit_code = 2 { threshold for line_skip instead of baseline_skip }
define hsize_code = 3 { line width in horizontal mode }
define vsize_code = 4 { page height in vertical mode }
define max_depth_code = 5 { maximum depth of boxes on main pages }
define split_max_depth_code = 6 { maximum depth of boxes on split pages }
define box_max_depth_code = 7 { maximum depth of explicit vboxes }
define hfuzz_code = 8 { tolerance for overfull hbox messages }
define vfuzz_code = 9 { tolerance for overfull vbox messages }
define delimiter_shortfall_code = 10 { maximum amount uncovered by variable delimiters }
define null_delimiter_space_code = 11 { blank space in null delimiters }
define script_space_code = 12 { extra space after subscript or superscript }
define pre_display_size_code = 13 { length of text preceding a display }
define display_width_code = 14 { length of line for displayed equation }
define display_indent_code = 15 { indentation of line for displayed equation }
define overfull_rule_code = 16 { width of rule that identifies overfull hboxes }
define hang_indent_code = 17 { amount of hanging indentation }
define h_offset_code = 18 { amount of horizontal offset when shipping pages out }
define v_offset_code = 19 { amount of vertical offset when shipping pages out }
define emergency_stretch_code = 20 { reduces badnesses on final pass of line-breaking }
define pdftex_first_dimen_code = 21 { first number defined in this section }
define pdf_h_origin_code = pdftex_first_dimen_code + 0 { horigin of the PDF output }
define pdf_v_origin_code = pdftex_first_dimen_code + 1 { vorigin of the PDF output }
define pdf_page_width_code = pdftex_first_dimen_code + 2 { page width of the PDF output }
define pdf_page_height_code = pdftex_first_dimen_code + 3 { page height of the PDF output }
define pdf_link_margin_code = pdftex_first_dimen_code + 4 { link margin in the PDF output }
define pdf_dest_margin_code = pdftex_first_dimen_code + 5 { dest margin in the PDF output }
define pdf_thread_margin_code = pdftex_first_dimen_code + 6 { thread margin in the PDF output }
define pdf_first_line_height_code = pdftex_first_dimen_code + 7
define pdf_last_line_depth_code = pdftex_first_dimen_code + 8
define pdf_each_line_height_code = pdftex_first_dimen_code + 9
define pdf_each_line_depth_code = pdftex_first_dimen_code + 10
define pdf_ignored_dimen_code = pdftex_first_dimen_code + 11
define pdf_px_dimen_code = pdftex_first_dimen_code + 12
define pdftex_last_dimen_code = pdftex_first_dimen_code + 12 { last number defined in this section }
define dimen_pars = pdftex_last_dimen_code + 1 { total number of dimension parameters }
define scaled_base = dimen_base + dimen_pars { table of 256 user-defined \dimen registers }
define eqtb_size = scaled_base + 255 { largest subscript of eqtb }

define dimen(#) ≡ eqtb[scaled_base + #].sc
define dimen_par(#) ≡ eqtb[dimen_base + #].sc { a scaled quantity }
define par_indent ≡ dimen_par(par_indent_code)
define math_surround ≡ dimen_par(math_surround_code)
define line_skip_limit ≡ dimen_par(line_skip_limit_code)
define hsize ≡ dimen_par(hsize_code)
define vsize ≡ dimen_par(vsize_code)
define max_depth ≡ dimen_par(max_depth_code)
define split_max_depth ≡ dimen_par(split_max_depth_code)
define box_max_depth ≡ dimen_par(box_max_depth_code)
define hfuzz ≡ dimen_par(hfuzz_code)
define vfuzz ≡ dimen_par(vfuzz_code)

```

```

define delimiter_shortfall  $\equiv$  dimen_par(delimiter_shortfall_code)
define null_delimiter_space  $\equiv$  dimen_par(null_delimiter_space_code)
define script_space  $\equiv$  dimen_par(script_space_code)
define pre_display_size  $\equiv$  dimen_par(pre_display_size_code)
define display_width  $\equiv$  dimen_par(display_width_code)
define display_indent  $\equiv$  dimen_par(display_indent_code)
define overfull_rule  $\equiv$  dimen_par(overfull_rule_code)
define hang_indent  $\equiv$  dimen_par(hang_indent_code)
define h_offset  $\equiv$  dimen_par(h_offset_code)
define v_offset  $\equiv$  dimen_par(v_offset_code)
define emergency_stretch  $\equiv$  dimen_par(emergency_stretch_code)
define pdf_h_origin  $\equiv$  dimen_par(pdf_h_origin_code)
define pdf_v_origin  $\equiv$  dimen_par(pdf_v_origin_code)
define pdf_page_width  $\equiv$  dimen_par(pdf_page_width_code)
define pdf_page_height  $\equiv$  dimen_par(pdf_page_height_code)
define pdf_link_margin  $\equiv$  dimen_par(pdf_link_margin_code)
define pdf_dest_margin  $\equiv$  dimen_par(pdf_dest_margin_code)
define pdf_thread_margin  $\equiv$  dimen_par(pdf_thread_margin_code)
define pdf_first_line_height  $\equiv$  dimen_par(pdf_first_line_height_code)
define pdf_last_line_depth  $\equiv$  dimen_par(pdf_last_line_depth_code)
define pdf_each_line_height  $\equiv$  dimen_par(pdf_each_line_height_code)
define pdf_each_line_depth  $\equiv$  dimen_par(pdf_each_line_depth_code)
define pdf_ignored_dimen  $\equiv$  dimen_par(pdf_ignored_dimen_code)
define pdf_px_dimen  $\equiv$  dimen_par(pdf_px_dimen_code)

```

```

procedure print_length_param(n : integer);
begin case n of
  par_indent_code: print_esc("parindent");
  math_surround_code: print_esc("mathsurround");
  line_skip_limit_code: print_esc("lineskiplimit");
  hsize_code: print_esc("hsize");
  vsize_code: print_esc("vsize");
  max_depth_code: print_esc("maxdepth");
  split_max_depth_code: print_esc("splitmaxdepth");
  box_max_depth_code: print_esc("boxmaxdepth");
  hfuzz_code: print_esc("hfuzz");
  vfuzz_code: print_esc("vfuzz");
  delimiter_shortfall_code: print_esc("delimitershortfall");
  null_delimiter_space_code: print_esc("nulldelimiterspace");
  script_space_code: print_esc("scriptspace");
  pre_display_size_code: print_esc("predisplaysize");
  display_width_code: print_esc("displaywidth");
  display_indent_code: print_esc("displayindent");
  overfull_rule_code: print_esc("overfullrule");
  hang_indent_code: print_esc("hangindent");
  h_offset_code: print_esc("hoffset");
  v_offset_code: print_esc("voffset");
  emergency_stretch_code: print_esc("emergencystretch");
  pdf_h_origin_code: print_esc("pdfhorigin");
  pdf_v_origin_code: print_esc("pdfvorigin");
  pdf_page_width_code: print_esc("pdfpagewidth");
  pdf_page_height_code: print_esc("pdfpageheight");
  pdf_link_margin_code: print_esc("pdflinkmargin");

```

```

pdf_dest_margin_code: print_esc("pdfdestmargin");
pdf_thread_margin_code: print_esc("pdfthreadmargin");
pdf_first_line_height_code: print_esc("pdffirstlineheight");
pdf_last_line_depth_code: print_esc("pdflastlinedepth");
pdf_each_line_height_code: print_esc("pdfeachlineheight");
pdf_each_line_depth_code: print_esc("pdfeachlinedepth");
pdf_ignored_dimen_code: print_esc("pdfignoredimen");
pdf_px_dimen_code: print_esc("pdfpxdimen");
othercases print("[unknown_dimen_parameter!]")
endcases;
end;

```

266. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```

primitive("parindent", assign_dimen, dimen_base + par_indent_code);
primitive("mathsurround", assign_dimen, dimen_base + math_surround_code);
primitive("lineskiplimit", assign_dimen, dimen_base + line_skip_limit_code);
primitive("hsize", assign_dimen, dimen_base + hsize_code);
primitive("vsize", assign_dimen, dimen_base + vsize_code);
primitive("maxdepth", assign_dimen, dimen_base + max_depth_code);
primitive("splitmaxdepth", assign_dimen, dimen_base + split_max_depth_code);
primitive("boxmaxdepth", assign_dimen, dimen_base + box_max_depth_code);
primitive("hfuzz", assign_dimen, dimen_base + hfuzz_code);
primitive("vfuzz", assign_dimen, dimen_base + vfuzz_code);
primitive("delimitershortfall", assign_dimen, dimen_base + delimiter_shortfall_code);
primitive("nulldelimiterspace", assign_dimen, dimen_base + null_delimiter_space_code);
primitive("scriptspace", assign_dimen, dimen_base + script_space_code);
primitive("predisplaysize", assign_dimen, dimen_base + pre_display_size_code);
primitive("displaywidth", assign_dimen, dimen_base + display_width_code);
primitive("displayindent", assign_dimen, dimen_base + display_indent_code);
primitive("overfullrule", assign_dimen, dimen_base + overfull_rule_code);
primitive("hangindent", assign_dimen, dimen_base + hang_indent_code);
primitive("hoffset", assign_dimen, dimen_base + h_offset_code);
primitive("voffset", assign_dimen, dimen_base + v_offset_code);
primitive("emergencystretch", assign_dimen, dimen_base + emergency_stretch_code);
primitive("pdfhorigin", assign_dimen, dimen_base + pdf_h_origin_code);
primitive("pdfvorigin", assign_dimen, dimen_base + pdf_v_origin_code);
primitive("pdfpagewidth", assign_dimen, dimen_base + pdf_page_width_code);
primitive("pdfpageheight", assign_dimen, dimen_base + pdf_page_height_code);
primitive("pdflinkmargin", assign_dimen, dimen_base + pdf_link_margin_code);
primitive("pdfdestmargin", assign_dimen, dimen_base + pdf_dest_margin_code);
primitive("pdfthreadmargin", assign_dimen, dimen_base + pdf_thread_margin_code);
primitive("pdffirstlineheight", assign_dimen, dimen_base + pdf_first_line_height_code);
primitive("pdflastlinedepth", assign_dimen, dimen_base + pdf_last_line_depth_code);
primitive("pdfeachlineheight", assign_dimen, dimen_base + pdf_each_line_height_code);
primitive("pdfeachlinedepth", assign_dimen, dimen_base + pdf_each_line_depth_code);
primitive("pdfignoredimen", assign_dimen, dimen_base + pdf_ignored_dimen_code);
primitive("pdfpxdimen", assign_dimen, dimen_base + pdf_px_dimen_code);

```

267. \langle Cases of `print_cmd_chr` for symbolic printing of primitives 245 $\rangle + \equiv$

```

assign_dimen: if chr_code < scaled_base then print_length_param(chr_code - dimen_base)
  else begin print_esc("dimen"); print_int(chr_code - scaled_base);
  end;

```

268. \langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$
for $k \leftarrow \text{dimen_base}$ **to** eqtb_size **do** $\text{eqtb}[k].sc \leftarrow 0$;

269. \langle Show equivalent n , in region 6 269 $\rangle \equiv$
begin if $n < \text{scaled_base}$ **then** $\text{print_length_param}(n - \text{dimen_base})$
else begin $\text{print_esc}(\text{"dimen"})$; $\text{print_int}(n - \text{scaled_base})$;
end;
 $\text{print_char}(\text{"="})$; $\text{print_scaled}(\text{eqtb}[n].sc)$; $\text{print}(\text{"pt"})$;
end

This code is used in section 270.

270. Here is a procedure that displays the contents of $\text{eqtb}[n]$ symbolically.

\langle Declare the procedure called print_cmd_chr 320 \rangle
stat procedure $\text{show_eqtb}(n : \text{pointer})$;
begin if $n < \text{active_base}$ **then** $\text{print_char}(\text{"?"})$ { this can't happen }
else if $n < \text{glue_base}$ **then** \langle Show equivalent n , in region 1 or 2 241 \rangle
else if $n < \text{local_base}$ **then** \langle Show equivalent n , in region 3 247 \rangle
else if $n < \text{int_base}$ **then** \langle Show equivalent n , in region 4 251 \rangle
else if $n < \text{dimen_base}$ **then** \langle Show equivalent n , in region 5 260 \rangle
else if $n \leq \text{eqtb_size}$ **then** \langle Show equivalent n , in region 6 269 \rangle
else $\text{print_char}(\text{"?"})$; { this can't happen either }
end;
tats

271. The last two regions of eqtb have fullword values instead of the three fields eq_level , eq_type , and equiv . An eq_type is unnecessary, but TeX needs to store the eq_level information in another array called xreq_level .

\langle Global variables 13 $\rangle + \equiv$
 eqtb : **array** [$\text{active_base} .. \text{eqtb_size}$] **of** memory_word ;
 xreq_level : **array** [$\text{int_base} .. \text{eqtb_size}$] **of** quarterword ;

272. \langle Set initial values of key variables 21 $\rangle + \equiv$
for $k \leftarrow \text{int_base}$ **to** eqtb_size **do** $\text{xreq_level}[k] \leftarrow \text{level_one}$;

273. When the debugging routine search_mem is looking for pointers having a given value, it is interested only in regions 1 to 3 of eqtb , and in the first part of region 4.

\langle Search eqtb for equivalents equal to p 273 $\rangle \equiv$
for $q \leftarrow \text{active_base}$ **to** $\text{box_base} + 255$ **do**
begin if $\text{equiv}(q) = p$ **then**
begin $\text{print_nl}(\text{"EQUIV"})$; $\text{print_int}(q)$; $\text{print_char}(\text{" "})$;
end;
end

This code is used in section 190.

274. The hash table. Control sequences are stored and retrieved by means of a fairly standard hash table algorithm called the method of “coalescing lists” (cf. Algorithm 6.4C in *The Art of Computer Programming*). Once a control sequence enters the table, it is never removed, because there are complicated situations involving `\gdef` where the removal of a control sequence at the end of a group would be a mistake preventable only by the introduction of a complicated reference-count mechanism.

The actual sequence of letters forming a control sequence identifier is stored in the *str_pool* array together with all the other strings. An auxiliary array *hash* consists of items with two halfword fields per word. The first of these, called *next*(*p*), points to the next identifier belonging to the same coalesced list as the identifier corresponding to *p*; and the other, called *text*(*p*), points to the *str_start* entry for *p*’s identifier. If position *p* of the hash table is empty, we have *text*(*p*) = 0; if position *p* is either empty or the end of a coalesced hash list, we have *next*(*p*) = 0. An auxiliary pointer variable called *hash_used* is maintained in such a way that all locations *p* ≥ *hash_used* are nonempty. The global variable *cs_count* tells how many multiletter control sequences have been defined, if statistics are being kept.

A global boolean variable called *no_new_control_sequence* is set to *true* during the time that new hash table entries are forbidden.

```

define next(#) ≡ hash[#].lh    { link for coalesced lists }
define text(#) ≡ hash[#].rh    { string number for control sequence name }
define hash_is_full ≡ (hash_used = hash_base)  { test if all positions are occupied }
define font_id_text(#) ≡ text(font_id_base + #) { a frozen font identifier’s name }

⟨Global variables 13⟩ +=
hash: array [hash_base .. undefined_control_sequence - 1] of two_halves; { the hash table }
hash_used: pointer; { allocation pointer for hash }
no_new_control_sequence: boolean; { are new identifiers legal? }
cs_count: integer; { total number of known identifiers }
```

275. Primitive support needs a few extra variables and definitions

```

define prim_prime = 1777 { about 85% of primitive_size }
define prim_base = 1
define prim_next(#) ≡ prim[#].lh    { link for coalesced lists }
define prim_text(#) ≡ prim[#].rh    { string number for control sequence name, plus one }
define prim_is_full ≡ (prim_used = prim_base)  { test if all positions are occupied }
define prim_eq_level_field(#) ≡ #.hh.b1
define prim_eq_type_field(#) ≡ #.hh.b0
define prim_equiv_field(#) ≡ #.hh.rh
define prim_eq_level(#) ≡ prim_eq_level_field(eqtb[prim_eqtb_base + #]) { level of definition }
define prim_eq_type(#) ≡ prim_eq_type_field(eqtb[prim_eqtb_base + #]) { command code for equivalent }
define prim_equiv(#) ≡ prim_equiv_field(eqtb[prim_eqtb_base + #]) { equivalent value }
define undefined_primitive = 0
define biggest_char = 255 { 65535 in XeTeX }

⟨Global variables 13⟩ +=
prim: array [0 .. prim_size] of two_halves; { the primitives table }
prim_used: pointer; { allocation pointer for prim }
```

276. ⟨Set initial values of key variables 21⟩ +=

```

no_new_control_sequence ← true; { new identifiers are usually forbidden }
prim_next(0) ← 0; prim_text(0) ← 0;
for k ← 1 to prim_size do prim[k] ← prim[0];
next(hash_base) ← 0; text(hash_base) ← 0;
for k ← hash_base + 1 to undefined_control_sequence - 1 do hash[k] ← hash[hash_base];
```

277. \langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$

```

prim_used  $\leftarrow$  prim_size; { nothing is used }
hash_used  $\leftarrow$  frozen_control_sequence; { nothing is used }
cs_count  $\leftarrow$  0; eq_type(frozen_dont_expand)  $\leftarrow$  dont_expand;
text(frozen_dont_expand)  $\leftarrow$  "notexpanded: "; eq_type(frozen_primitive)  $\leftarrow$  ignore_spaces;
equiv(frozen_primitive)  $\leftarrow$  1; eq_level(frozen_primitive)  $\leftarrow$  level_one;
text(frozen_primitive)  $\leftarrow$  "pdfprimitive";

```

278. Here is the subroutine that searches the hash table for an identifier that matches a given string of length $l > 1$ appearing in $buffer[j \dots (j + l - 1)]$. If the identifier is found, the corresponding hash table address is returned. Otherwise, if the global variable *no_new_control_sequence* is *true*, the dummy address *undefined_control_sequence* is returned. Otherwise the identifier is inserted into the hash table and its location is returned.

```

function id_lookup( $j, l$  : integer): pointer; { search the hash table }
  label found; { go here if you found it }
  var h: integer; { hash code }
      d: integer; { number of characters in incomplete current string }
      p: pointer; { index in hash array }
      k: pointer; { index in buffer array }
  begin  $\langle$  Compute the hash code  $h$  280  $\rangle$ ;
   $p \leftarrow h + hash\_base$ ; { we start searching here; note that  $0 \leq h < hash\_prime$  }
  loop begin if text( $p$ ) > 0 then
    if length(text( $p$ )) =  $l$  then
      if str_eq_buf(text( $p$ ),  $j$ ) then goto found;
    if next( $p$ ) = 0 then
      begin if no_new_control_sequence then  $p \leftarrow undefined\_control\_sequence$ 
      else  $\langle$  Insert a new control sequence after  $p$ , then make  $p$  point to it 279  $\rangle$ ;
      goto found;
      end;
     $p \leftarrow next(p)$ ;
  end;
found: id_lookup  $\leftarrow$   $p$ ;
end;

```

279. \langle Insert a new control sequence after p , then make p point to it 279 $\rangle \equiv$

```

begin if text( $p$ ) > 0 then
  begin repeat if hash_is_full then overflow("hash_size", hash_size);
    decr(hash_used);
  until text(hash_used) = 0; { search for an empty location in hash }
  next( $p$ )  $\leftarrow$  hash_used;  $p \leftarrow$  hash_used;
  end;
  str_room( $l$ );  $d \leftarrow cur\_length$ ;
  while pool_ptr > str_start[str_ptr] do
    begin decr(pool_ptr); str_pool[pool_ptr +  $l$ ]  $\leftarrow$  str_pool[pool_ptr];
    end; { move current string up to make room for another }
  for  $k \leftarrow j$  to  $j + l - 1$  do append_char(buffer[ $k$ ]);
  text( $p$ )  $\leftarrow$  make_string; pool_ptr  $\leftarrow$  pool_ptr +  $d$ ;
  stat incr(cs_count); tats
end

```

This code is used in section 278.

280. The value of *hash_prime* should be roughly 85% of *hash_size*, and it should be a prime number. The theory of hashing tells us to expect fewer than two table probes, on the average, when the search is successful. [See J. S. Vitter, *Journal of the ACM* **30** (1983), 231–258.]

```

⟨ Compute the hash code h 280 ⟩ ≡
  h ← buffer[j];
  for k ← j + 1 to j + l − 1 do
    begin h ← h + h + buffer[k];
    while h ≥ hash_prime do h ← h − hash_prime;
  end

```

This code is used in section 278.

281. Here is the subroutine that searches the primitive table for an identifier:

```

function prim_lookup(s : str_number): pointer; { search the primitives table }
  label found; { go here if you found it }
  var h: integer; { hash code }
  p: pointer; { index in hash array }
  k: pointer; { index in string pool }
  j, l: integer;
  begin if s ≤ biggest_char then
    begin if s < 0 then
      begin p ← undefined_primitive; goto found;
    end
    else p ← (s mod prim_prime) + prim_base; { we start searching here }
    end
  else begin j ← str_start[s];
    if s = str_ptr then l ← cur_length
    else l ← length(s);
    ⟨ Compute the primitive code h 283 ⟩;
    p ← h + prim_base; { we start searching here; note that 0 ≤ h < prim_prime }
    end;
    loop begin if prim_text(p) > 1 + biggest_char then { p points a multi-letter primitive }
      begin if length(prim_text(p) − 1) = l then
        if str_eq_str(prim_text(p) − 1, s) then goto found;
      end
    else if prim_text(p) = 1 + s then goto found; { p points a single-letter primitive }
    if prim_next(p) = 0 then
      begin if no_new_control_sequence then p ← undefined_primitive
      else ⟨ Insert a new primitive after p, then make p point to it 282 ⟩;
      goto found;
    end;
    p ← prim_next(p);
    end;
  found: prim_lookup ← p;
  end;

```


282. \langle Insert a new primitive after p , then make p point to it 282 $\rangle \equiv$

```

begin if  $\text{prim\_text}(p) > 0$  then
  begin repeat if  $\text{prim\_is\_full}$  then  $\text{overflow}(\text{"primitive\_size"}, \text{prim\_size});$ 
     $\text{decr}(\text{prim\_used});$ 
  until  $\text{prim\_text}(\text{prim\_used}) = 0;$  { search for an empty location in  $\text{prim}$  }
   $\text{prim\_next}(p) \leftarrow \text{prim\_used}; p \leftarrow \text{prim\_used};$ 
end;
 $\text{prim\_text}(p) \leftarrow s + 1;$ 
end

```

This code is used in section 281.

283. The value of prim_prime should be roughly 85% of prim_size , and it should be a prime number.

\langle Compute the primitive code h 283 $\rangle \equiv$

```

 $h \leftarrow \text{str\_pool}[j];$ 
for  $k \leftarrow j + 1$  to  $j + l - 1$  do
  begin  $h \leftarrow h + h + \text{str\_pool}[k];$ 
  while  $h \geq \text{prim\_prime}$  do  $h \leftarrow h - \text{prim\_prime};$ 
end

```

This code is used in section 281.

284. Single-character control sequences do not need to be looked up in a hash table, since we can use the character code itself as a direct address. The procedure print_cs prints the name of a control sequence, given a pointer to its address in eqtb . A space is printed after the name unless it is a single nonletter or an active character. This procedure might be invoked with invalid data, so it is “extra robust.” The individual characters must be printed one at a time using print , since they may be unprintable.

\langle Basic printing procedures 57 $\rangle + \equiv$

```

procedure  $\text{print\_cs}(p : \text{integer});$  { prints a purported control sequence }
  begin if  $p < \text{hash\_base}$  then { single character }
    if  $p \geq \text{single\_base}$  then
      if  $p = \text{null\_cs}$  then
        begin  $\text{print\_esc}(\text{"csname"}); \text{print\_esc}(\text{"endcsname"}); \text{print\_char}(\text{"_"});$ 
        end
      else begin  $\text{print\_esc}(p - \text{single\_base});$ 
        if  $\text{cat\_code}(p - \text{single\_base}) = \text{letter}$  then  $\text{print\_char}(\text{"_"});$ 
        end
      else if  $p < \text{active\_base}$  then  $\text{print\_esc}(\text{"IMPOSSIBLE."})$ 
        else  $\text{print}(p - \text{active\_base})$ 
      else if  $p \geq \text{undefined\_control\_sequence}$  then  $\text{print\_esc}(\text{"IMPOSSIBLE."})$ 
        else if  $(\text{text}(p) < 0) \vee (\text{text}(p) \geq \text{str\_ptr})$  then  $\text{print\_esc}(\text{"NONEXISTENT."})$ 
          else begin if  $(p \geq \text{prim\_eqtb\_base}) \wedge (p < \text{frozen\_null\_font})$  then
             $\text{print\_esc}(\text{prim\_text}(p - \text{prim\_eqtb\_base}) - 1)$ 
          else  $\text{print\_esc}(\text{text}(p));$ 
             $\text{print\_char}(\text{"_"});$ 
          end;
        end;
      end;

```

285. Here is a similar procedure; it avoids the error checks, and it never prints a space after the control sequence.

⟨ Basic printing procedures 57 ⟩ +≡

```
procedure sprint_cs(p : pointer); { prints a control sequence }
begin if p < hash_base then
  if p < single_base then print(p − active_base)
  else if p < null_cs then print_esc(p − single_base)
    else begin print_esc("csname"); print_esc("endcsname");
    end
else if (p ≥ prim_eqtb_base) ∧ (p < frozen_null_font) then print_esc(prim_text(p − prim_eqtb_base) − 1)
  else print_esc(text(p));
end;
```

286. We need to put TeX’s “primitive” control sequences into the hash table, together with their command code (which will be the *eq_type*) and an operand (which will be the *equiv*). The *primitive* procedure does this, in a way that no TeX user can. The global value *cur_val* contains the new *eqtb* pointer after *primitive* has acted.

Until pdfTeX 1.40.19 (released in 2018), a bug in primitive handling caused, e.g., `\pdfprimitive\ \q` to swallow the `\q` instead of giving an undefined control sequence error. The original report was posted by Hironori Kitagawa (tug.org/pipermail/tex-k/2017-October/002816.html). Largely quoting from that message:

The cause was *cur_tok* not being set in the “Cases of *main_control...*” module, because *back_input* unscans the token, but only looks at *cur_tok*, which represents the internalized `\pdfprimitive` at that time. So `\pdfprimitive\vrule\q` becomes “(internalized `\pdfprimitive`)”`\q`, hence no error (and `\vrule` disappears).

Hironori’s explanation of the previous behavior and fix continues (off-list):

- * *back_input* (and similar routine `<Insert token p into TeX’s input>`) only stores *cur_tok* to a token list.
- * When TeX gets input from a token list (at module `<Input from token list, goto restart ...>`), TeX looks at the saved *cur_tok* value *t*, and recover the command code (*cur_cmd*) and its modifier (*cur_chr*) from it:
 - If $t \geq cs_token_flag$, *t* points to an *eqtb* location $t - cs_token_flag$.
 - If $t < cs_token_flag$, *cur_cmd* and *cur_chr* are set with $cur_cmd \leftarrow t \text{div } '400$; $cur_chr \leftarrow t \text{mod } '400$.
 - This *t* is used to display the token (*show_token_list*).
- * pdfTeX defines *cs_token_flag* as “FFF”. So simply using $cur_tok \leftarrow (cur_cmd * '400) + cur_chr$ by `\pdfprimitive` does not work correctly with primitives whose command codes $cur_cmd \geq 16$.

Increasing *cs_token_flag* to “FFFF” or somewhat higher might suffice for fixing this situation in pdfTeX. However, this approach does not seem good, because

- 1) an (indirect) mapping from *cur_tok* to control sequence name is needed anyway, for displaying the token, and
- 2) this does not work in Japanese e-(u)pTeX.

Thus, we now put *prim_eqtb* entries into the end of region 2 of *eqtb* (which contains some frozen primitives, such as “frozen `\fi`” and “frozen `\cr`”), thus treating *prim_eqtb* entries as a permanent location for primitives.

init procedure *primitive*(*s* : *str_number*; *c* : *quarterword*; *o* : *halfword*);

var *k*: *pool_pointer*; { index into *str_pool* }

j: 0 .. *buf_size*; { index into *buffer* }

l: *small_number*; { length of the string }

prim_val: *integer*; { needed to fill *prim_eqtb* }

begin if *s* < 256 **then**

begin *cur_val* $\leftarrow s + single_base$; *prim_val* $\leftarrow prim_lookup(s)$;

end

else begin *k* $\leftarrow str_start[s]$; *l* $\leftarrow str_start[s + 1] - k$;

 { we will move *s* into the (possibly non-empty) *buffer* }

if *first* + *l* > *buf_size* + 1 **then** *overflow*(“buffer_size”, *buf_size*);

for *j* $\leftarrow 0$ **to** *l* - 1 **do** *buffer*[*first* + *j*] $\leftarrow so(str_pool[k + j])$;

cur_val $\leftarrow id_lookup(first, l)$; { *no_new_control_sequence* is false }

flush_string; *text*(*cur_val*) $\leftarrow s$; { we don’t want to have the string twice }

prim_val $\leftarrow prim_lookup(s)$;

end;

eq_level(*cur_val*) $\leftarrow level_one$; *eq_type*(*cur_val*) $\leftarrow c$; *equiv*(*cur_val*) $\leftarrow o$;

prim_eq_level(*prim_val*) $\leftarrow level_one$; *prim_eq_type*(*prim_val*) $\leftarrow c$; *prim_equiv*(*prim_val*) $\leftarrow o$;

end;

tini

287. Many of TeX's primitives need no *equiv*, since they are identifiable by their *eq_type* alone. These primitives are loaded into the hash table as follows:

```

⟨ Put each of TeX's primitives into the hash table 244 ⟩ +≡
  primitive("□", ex_space, 0);
  primitive("/", ital_corr, 0);
  primitive("accent", accent, 0);
  primitive("advance", advance, 0);
  primitive("afterassignment", after_assignment, 0);
  primitive("aftergroup", after_group, 0);
  primitive("begingroup", begin_group, 0);
  primitive("char", char_num, 0);
  primitive("csname", cs_name, 0);
  primitive("delimiter", delim_num, 0);
  primitive("divide", divide, 0);
  primitive("endcsname", end_cs_name, 0);
  primitive("endgroup", end_group, 0); text(frozen_end_group) ← "endgroup";
  eqtb[frozen_end_group] ← eqtb[cur_val];
  primitive("expandafter", expand_after, 0);
  primitive("font", def_font, 0);
  primitive("letterspacefont", letterspace_font, 0);
  primitive("pdfcopyfont", pdf_copy_font, 0);
  primitive("fontdimen", assign_font_dimen, 0);
  primitive("halign", halign, 0);
  primitive("hrule", hrule, 0);
  primitive("ignorespaces", ignore_spaces, 0);
  primitive("insert", insert, 0);
  primitive("mark", mark, 0);
  primitive("mathaccent", math_accent, 0);
  primitive("mathchar", math_char_num, 0);
  primitive("mathchoice", math_choice, 0);
  primitive("multiply", multiply, 0);
  primitive("noalign", no_align, 0);
  primitive("noboundary", no_boundary, 0);
  primitive("noexpand", no_expand, 0);
  primitive("pdfprimitive", no_expand, 1);
  primitive("nonscript", non_script, 0);
  primitive("omit", omit, 0);
  primitive("parshape", set_shape, par_shape_loc);
  primitive("penalty", break_penalty, 0);
  primitive("prevgraf", set_prev_graf, 0);
  primitive("radical", radical, 0);
  primitive("read", read_to_cs, 0);
  primitive("relax", relax, 256); { cf. scan_file_name }
  text(frozen_relax) ← "relax"; eqtb[frozen_relax] ← eqtb[cur_val];
  primitive("setbox", set_box, 0);
  primitive("the", the, 0);
  primitive("toks", toks_register, mem_bot);
  primitive("vadjust", vadjust, 0);
  primitive("valign", valign, 0);
  primitive("vcenter", vcenter, 0);
  primitive("vrule", vrule, 0);

```

288. Each primitive has a corresponding inverse, so that it is possible to display the cryptic numeric contents of *eqtb* in symbolic form. Every call of *primitive* in this program is therefore accompanied by some straightforward code that forms part of the *print_cmd_chr* routine below.

```

⟨ Cases of print_cmd_chr for symbolic printing of primitives 245 ⟩ +=
accent: print_esc("accent");
advance: print_esc("advance");
after_assignment: print_esc("afterassignment");
after_group: print_esc("aftergroup");
assign_font_dimen: print_esc("fontdimen");
begin_group: print_esc("begingroup");
break_penalty: print_esc("penalty");
char_num: print_esc("char");
cs_name: print_esc("csname");
def_font: print_esc("font");
letterspace_font: print_esc("letterspacefont");
pdf_copy_font: print_esc("pdfcopyfont");
delim_num: print_esc("delimiter");
divide: print_esc("divide");
end_cs_name: print_esc("endcsname");
end_group: print_esc("endgroup");
ex_space: print_esc("□");
expand_after: if chr_code = 0 then print_esc("expandafter")
    ⟨ Cases of expandafter for print_cmd_chr 1760 ⟩;
halign: print_esc("halign");
hrule: print_esc("hrule");
ignore_spaces: if chr_code = 0 then print_esc("ignorespaces")
    else print_esc("pdfprimitive");
insert: print_esc("insert");
ital_corr: print_esc("/");
mark: begin print_esc("mark");
    if chr_code > 0 then print_char("s");
end;
math_accent: print_esc("mathaccent");
math_char_num: print_esc("mathchar");
math_choice: print_esc("mathchoice");
multiply: print_esc("multiply");
no_align: print_esc("noalign");
no_boundary: print_esc("noboundary");
no_expand: if chr_code = 0 then print_esc("noexpand")
    else print_esc("pdfprimitive");
non_script: print_esc("nonscript");
omit: print_esc("omit");
radical: print_esc("radical");
read_to_cs: if chr_code = 0 then print_esc("read") ⟨ Cases of read for print_cmd_chr 1757 ⟩;
relax: print_esc("relax");
set_box: print_esc("setbox");
set_prev_graf: print_esc("prevgraf");
set_shape: case chr_code of
    par_shape_loc: print_esc("parshape");
    ⟨ Cases of set_shape for print_cmd_chr 1862 ⟩
end; { there are no other cases }
the: if chr_code = 0 then print_esc("the") ⟨ Cases of the for print_cmd_chr 1684 ⟩;

```

```

toks_register: ⟨ Cases of toks_register for print_cmd_chr 1830 ⟩;
vadjust: print_esc("vadjust");
valign: if chr_code = 0 then print_esc("valign")
  ⟨ Cases of valign for print_cmd_chr 1699 ⟩;
vcenter: print_esc("vcenter");
vrule: print_esc("vrule");

```

289. We will deal with the other primitives later, at some point in the program where their *eq_type* and *equiv* values are more meaningful. For example, the primitives for math mode will be loaded when we consider the routines that deal with formulas. It is easy to find where each particular primitive was treated by looking in the index at the end; for example, the section where "radical" entered *eqtb* is listed under 'radical primitive'. (Primitives consisting of a single nonalphabetic character, like '\/', are listed under 'Single-character primitives'.)

Meanwhile, this is a convenient place to catch up on something we were unable to do before the hash table was defined:

290. Saving and restoring equivalents. The nested structure provided by ‘{...}’ groups in TeX means that *eqtb* entries valid in outer groups should be saved and restored later if they are overridden inside the braces. When a new *eqtb* value is being assigned, the program therefore checks to see if the previous entry belongs to an outer level. In such a case, the old value is placed on the *save_stack* just before the new value enters *eqtb*. At the end of a grouping level, i.e., when the right brace is sensed, the *save_stack* is used to restore the outer values, and the inner ones are destroyed.

Entries on the *save_stack* are of type *memory_word*. The top item on this stack is *save_stack*[*p*], where *p* = *save_ptr* − 1; it contains three fields called *save_type*, *save_level*, and *save_index*, and it is interpreted in one of five ways:

- 1) If *save_type*(*p*) = *restore_old_value*, then *save_index*(*p*) is a location in *eqtb* whose current value should be destroyed at the end of the current group and replaced by *save_stack*[*p* − 1]. Furthermore if *save_index*(*p*) ≥ *int_base*, then *save_level*(*p*) should replace the corresponding entry in *xeq_level*.
- 2) If *save_type*(*p*) = *restore_zero*, then *save_index*(*p*) is a location in *eqtb* whose current value should be destroyed at the end of the current group, when it should be replaced by the value of *eqtb*[*undefined_control_sequence*].
- 3) If *save_type*(*p*) = *insert_token*, then *save_index*(*p*) is a token that should be inserted into TeX’s input when the current group ends.
- 4) If *save_type*(*p*) = *level_boundary*, then *save_level*(*p*) is a code explaining what kind of group we were previously in, and *save_index*(*p*) points to the level boundary word at the bottom of the entries for that group. Furthermore, in extended ε-TeX mode, *save_stack*[*p* − 1] contains the source line number at which the current level of grouping was entered.
- 5) If *save_type*(*p*) = *restore_sa*, then *sa_chain* points to a chain of sparse array entries to be restored at the end of the current group. Furthermore *save_index*(*p*) and *save_level*(*p*) should replace the values of *sa_chain* and *sa_level* respectively.

```

define save_type(#) ≡ save_stack[#].hh.b0  { classifies a save_stack entry }
define save_level(#) ≡ save_stack[#].hh.b1  { saved level for regions 5 and 6, or group code }
define save_index(#) ≡ save_stack[#].hh.rh  { eqtb location or token or save_stack location }
define restore_old_value = 0  { save_type when a value should be restored later }
define restore_zero = 1  { save_type when an undefined entry should be restored }
define insert_token = 2  { save_type when a token is being saved for later use }
define level_boundary = 3  { save_type corresponding to beginning of group }
define restore_sa = 4  { save_type when sparse array entries should be restored }

```

⟨ Declare ε-TeX procedures for tracing and input 306 ⟩

291. Here are the group codes that are used to discriminate between different kinds of groups. They allow TeX to decide what special actions, if any, should be performed when a group ends.

Some groups are not supposed to be ended by right braces. For example, the ‘\$’ that begins a math formula causes a *math_shift_group* to be started, and this should be terminated by a matching ‘\$’. Similarly, a group that starts with `\left` should end with `\right`, and one that starts with `\begingroup` should end with `\endgroup`.

```

define bottom_level = 0   { group code for the outside world }
define simple_group = 1    { group code for local structure only }
define hbox_group = 2     { code for ‘\hbox{...}’ }
define adjusted_hbox_group = 3 { code for ‘\hbox{...}’ in vertical mode }
define vbox_group = 4     { code for ‘\vbox{...}’ }
define vtop_group = 5     { code for ‘\vtop{...}’ }
define align_group = 6    { code for ‘\halign{...}’, ‘\valign{...}’ }
define no_align_group = 7  { code for ‘\noalign{...}’ }
define output_group = 8   { code for output routine }
define math_group = 9     { code for, e.g., ‘^{...}’ }
define disc_group = 10    { code for ‘\discretionary{...}{...}{...}’ }
define insert_group = 11  { code for ‘\insert{...}’, ‘\vadjust{...}’ }
define vcenter_group = 12 { code for ‘\vcenter{...}’ }
define math_choice_group = 13 { code for ‘\mathchoice{...}{...}{...}{...}’ }
define semi_simple_group = 14 { code for ‘\begingroup... \endgroup’ }
define math_shift_group = 15 { code for ‘$...$’ }
define math_left_group = 16 { code for ‘\left... \right’ }
define max_group_code = 16

```

⟨Types in the outer block 18⟩ +≡

```
group_code = 0 .. max_group_code; { save_level for a level boundary }
```

292. The global variable *cur_group* keeps track of what sort of group we are currently in. Another global variable, *cur_boundary*, points to the topmost *level_boundary* word. And *cur_level* is the current depth of nesting. The routines are designed to preserve the condition that no entry in the *save_stack* or in *eqtb* ever has a level greater than *cur_level*.

293. ⟨Global variables 13⟩ +≡

```

save_stack: array [0 .. save_size] of memory_word;
save_ptr: 0 .. save_size; { first unused entry on save_stack }
max_save_stack: 0 .. save_size; { maximum usage of save stack }
cur_level: quarterword; { current nesting level for groups }
cur_group: group_code; { current group type }
cur_boundary: 0 .. save_size; { where the current level begins }

```

294. At this time it might be a good idea for the reader to review the introduction to *eqtb* that was given above just before the long lists of parameter names. Recall that the “outer level” of the program is *level_one*, since undefined control sequences are assumed to be “defined” at *level_zero*.

⟨Set initial values of key variables 21⟩ +≡

```
save_ptr ← 0; cur_level ← level_one; cur_group ← bottom_level; cur_boundary ← 0; max_save_stack ← 0;
```


295. The following macro is used to test if there is room for up to seven more entries on *save_stack*. By making a conservative test like this, we can get by with testing for overflow in only a few places.

```
define check_full_save_stack  $\equiv$ 
  if save_ptr > max_save_stack then
    begin max_save_stack  $\leftarrow$  save_ptr;
    if max_save_stack > save_size - 7 then overflow("save_size", save_size);
  end
```

296. Procedure *new_save_level* is called when a group begins. The argument is a group identification code like ‘*hbox_group*’. After calling this routine, it is safe to put five more entries on *save_stack*.

In some cases integer-valued items are placed onto the *save_stack* just below a *level_boundary* word, because this is a convenient place to keep information that is supposed to “pop up” just when the group has finished. For example, when ‘ $\hbox to 100pt\{...\}$ ’ is being treated, the 100pt dimension is stored on *save_stack* just before *new_save_level* is called.

We use the notation *saved(k)* to stand for an integer item that appears in location *save_ptr* + *k* of the save stack.

```
define saved( $\#$ )  $\equiv$  save_stack[save_ptr +  $\#$ ].int
procedure new_save_level(c : group_code); { begin a new level of grouping }
  begin check_full_save_stack;
  if eTeX_ex then
    begin saved(0)  $\leftarrow$  line; incr(save_ptr);
    end;
  save_type(save_ptr)  $\leftarrow$  level_boundary; save_level(save_ptr)  $\leftarrow$  cur_group;
  save_index(save_ptr)  $\leftarrow$  cur_boundary;
  if cur_level = max_quarterword then
    overflow("grouping_levels", max_quarterword - min_quarterword);
    { quit if (cur_level + 1) is too big to be stored in eqtb }
  cur_boundary  $\leftarrow$  save_ptr; cur_group  $\leftarrow$  c;
  stat if tracing_groups > 0 then group_trace(false);
  tats
  incr(cur_level); incr(save_ptr);
  end;
```

297. Just before an entry of *eqtb* is changed, the following procedure should be called to update the other data structures properly. It is important to keep in mind that reference counts in *mem* include references from within *save_stack*, so these counts must be handled carefully.

```
procedure eq_destroy(w : memory_word); { gets ready to forget w }
  var q: pointer; { equiv field of w }
  begin case eq_type_field(w) of
    call, long_call, outer_call, long_outer_call: delete_token_ref(equiv_field(w));
    glue_ref: delete_glue_ref(equiv_field(w));
    shape_ref: begin q  $\leftarrow$  equiv_field(w); { we need to free a \parshape block }
      if q  $\neq$  null then free_node(q, info(q) + info(q) + 1);
      end; { such a block is 2n + 1 words long, where n = info(q) }
    box_ref: flush_node_list(equiv_field(w));
     $\langle$  Cases for eq_destroy 1831  $\rangle$ 
  othercases do_nothing
  endcases;
  end;
```

298. To save a value of $eqtb[p]$ that was established at level l , we can use the following subroutine.

```
procedure eq_save( $p$  : pointer;  $l$  : quarterword); { saves  $eqtb[p]$  }
begin check_full_save_stack;
if  $l = \text{level\_zero}$  then save_type(save_ptr)  $\leftarrow$  restore_zero
else begin save_stack[save_ptr]  $\leftarrow$  eqtb[ $p$ ]; incr(save_ptr); save_type(save_ptr)  $\leftarrow$  restore_old_value;
  end;
  save_level(save_ptr)  $\leftarrow$   $l$ ; save_index(save_ptr)  $\leftarrow$   $p$ ; incr(save_ptr);
end;
```

299. The procedure *eq_define* defines an *eqtb* entry having specified *eq_type* and *equiv* fields, and saves the former value if appropriate. This procedure is used only for entries in the first four regions of *eqtb*, i.e., only for entries that have *eq_type* and *equiv* fields. After calling this routine, it is safe to put four more entries on *save_stack*, provided that there was room for four more entries before the call, since *eq_save* makes the necessary test.

```
define assign_trace(#)  $\equiv$ 
  stat if tracing_assigns > 0 then restore_trace(#);
  tats

procedure eq_define( $p$  : pointer;  $t$  : quarterword;  $e$  : halfword); { new data for  $eqtb$  }
label exit;
begin if  $eTeX\_ex \wedge (eq\_type(p) = t) \wedge (equiv(p) = e)$  then
  begin assign_trace( $p$ , "reassigning")
    eq_destroy(eqtb[ $p$ ]); return;
  end;
  assign_trace( $p$ , "changing")
if eq_level( $p$ ) = cur_level then eq_destroy(eqtb[ $p$ ])
else if cur_level > level_one then eq_save( $p$ , eq_level( $p$ ));
  eq_level( $p$ )  $\leftarrow$  cur_level; eq_type( $p$ )  $\leftarrow$   $t$ ; equiv( $p$ )  $\leftarrow$   $e$ ; assign_trace( $p$ , "into")
exit: end;
```

300. The counterpart of *eq_define* for the remaining (fullword) positions in *eqtb* is called *eq_word_define*. Since $xeq_level[p] \geq \text{level_one}$ for all p , a 'restore_zero' will never be used in this case.

```
procedure eq_word_define( $p$  : pointer;  $w$  : integer);
label exit;
begin if  $eTeX\_ex \wedge (eqtb[p].int = w)$  then
  begin assign_trace( $p$ , "reassigning")
    return;
  end;
  assign_trace( $p$ , "changing")
if xeq_level[ $p$ ]  $\neq$  cur_level then
  begin eq_save( $p$ , xeq_level[ $p$ ]); xeq_level[ $p$ ]  $\leftarrow$  cur_level;
  end;
  eqtb[ $p$ ].int  $\leftarrow$   $w$ ; assign_trace( $p$ , "into")
exit: end;
```

301. The *eq_define* and *eq_word_define* routines take care of local definitions. Global definitions are done in almost the same way, but there is no need to save old values, and the new value is associated with *level_one*.

```

procedure geq_define(p : pointer; t : quarterword; e : halfword); { global eq_define }
  begin assign_trace(p, "globally_changing")
  begin eq_destroy(eqtb[p]); eq_level(p) ← level_one; eq_type(p) ← t; equiv(p) ← e;
  end; assign_trace(p, "into")
  end;

procedure geq_word_define(p : pointer; w : integer); { global eq_word_define }
  begin assign_trace(p, "globally_changing")
  begin eqtb[p].int ← w; xeq_level[p] ← level_one;
  end; assign_trace(p, "into")
  end;

```

302. Subroutine *save_for_after* puts a token on the stack for save-keeping.

```

procedure save_for_after(t : halfword);
  begin if cur_level > level_one then
    begin check_full_save_stack; save_type(save_ptr) ← insert_token; save_level(save_ptr) ← level_zero;
    save_index(save_ptr) ← t; incr(save_ptr);
    end;
  end;

```

303. The *unsave* routine goes the other way, taking items off of *save_stack*. This routine takes care of restoration when a level ends; everything belonging to the topmost group is cleared off of the save stack.

```

procedure back_input; forward;
procedure unsave; { pops the top level off the save stack }
  label done;
  var p : pointer; { position to be restored }
  l : quarterword; { saved level, if in fullword regions of eqtb }
  t : halfword; { saved value of cur_tok }
  a : boolean; { have we already processed an \aftergroup ? }
  begin a ← false;
  if cur_level > level_one then
    begin decr(cur_level); { Clear off top level from save_stack 304 };
    end
  else confusion("curlevel"); { unsave is not used when cur_group = bottom_level }
  end;

```

304. \langle Clear off top level from *save_stack* 304 $\rangle \equiv$

```

loop begin decr(save_ptr);
  if save_type(save_ptr) = level_boundary then goto done;
  p  $\leftarrow$  save_index(save_ptr);
  if save_type(save_ptr) = insert_token then  $\langle$  Insert token p into TeX's input 348  $\rangle$ 
else if save_type(save_ptr) = restore_sa then
  begin sa_restore; sa_chain  $\leftarrow$  p; sa_level  $\leftarrow$  save_level(save_ptr);
  end
  else begin if save_type(save_ptr) = restore_old_value then
    begin l  $\leftarrow$  save_level(save_ptr); decr(save_ptr);
    end
    else save_stack[save_ptr]  $\leftarrow$  eqtb[undefined_control_sequence];
     $\langle$  Store save_stack[save_ptr] in eqtb[p], unless eqtb[p] holds a global value 305  $\rangle$ ;
    end;
  end;
done: stat if tracing_groups > 0 then group_trace(true);
tats
if grp_stack[in_open] = cur_boundary then group_warning;
  { groups possibly not properly nested with files }
cur_group  $\leftarrow$  save_level(save_ptr); cur_boundary  $\leftarrow$  save_index(save_ptr);
if eTeX_ex then decr(save_ptr)

```

This code is used in section 303.

305. A global definition, which sets the level to *level_one*, will not be undone by *unsave*. If at least one global definition of *eqtb*[*p*] has been carried out within the group that just ended, the last such definition will therefore survive.

\langle Store *save_stack*[*save_ptr*] in *eqtb*[*p*], unless *eqtb*[*p*] holds a global value 305 $\rangle \equiv$

```

if p < int_base then
  if eq_level(p) = level_one then
    begin eq_destroy(save_stack[save_ptr]); { destroy the saved value }
    stat if tracing_restores > 0 then restore_trace(p, "retaining");
    tats
    end
  else begin eq_destroy(eqtb[p]); { destroy the current value }
    eqtb[p]  $\leftarrow$  save_stack[save_ptr]; { restore the saved value }
    stat if tracing_restores > 0 then restore_trace(p, "restoring");
    tats
    end
  else if req_level[p]  $\neq$  level_one then
    begin eqtb[p]  $\leftarrow$  save_stack[save_ptr]; req_level[p]  $\leftarrow$  l;
    stat if tracing_restores > 0 then restore_trace(p, "restoring");
    tats
    end
  else begin stat if tracing_restores > 0 then restore_trace(p, "retaining");
    tats
    end

```

This code is used in section 304.

306. \langle Declare ε -TeX procedures for tracing and input 306 $\rangle \equiv$
stat procedure *restore_trace*(*p* : *pointer*; *s* : *str_number*); { *eqtb*[*p*] has just been restored or retained }
begin *begin_diagnostic*; *print_char*("{"); *print*(*s*); *print_char*(""); *show_eqtb*(*p*); *print_char*("}");
end_diagnostic(*false*);
end;
tats

See also sections 1658, 1659, 1753, 1754, 1771, 1773, 1774, 1818, 1820, 1834, 1835, 1836, 1837, and 1838.

This code is used in section 290.

307. When looking for possible pointers to a memory location, it is helpful to look for references from *eqtb* that might be waiting on the save stack. Of course, we might find spurious pointers too; but this routine is merely an aid when debugging, and at such times we are grateful for any scraps of information, even if they prove to be irrelevant.

\langle Search *save_stack* for equivalents that point to *p* 307 $\rangle \equiv$
if *save_ptr* > 0 **then**
 for *q* \leftarrow 0 **to** *save_ptr* - 1 **do**
 begin if *equiv_field*(*save_stack*[*q*]) = *p* **then**
 begin *print_nl*("SAVE("); *print_int*(*q*); *print_char*("");

end;

end

This code is used in section 190.

308. Most of the parameters kept in *eqtb* can be changed freely, but there's an exception: The magnification should not be used with two different values during any TeX job, since a single magnification is applied to an entire run. The global variable *mag_set* is set to the current magnification whenever it becomes necessary to “freeze” it at a particular value.

\langle Global variables 13 $\rangle + \equiv$
mag_set: *integer*; { if nonzero, this magnification should be used henceforth }

309. \langle Set initial values of key variables 21 $\rangle + \equiv$
mag_set \leftarrow 0;

310. The *prepare_mag* subroutine is called whenever TeX wants to use *mag* for magnification.

procedure *prepare_mag*;
begin if (*mag_set* > 0) \wedge (*mag* \neq *mag_set*) **then**
 begin *print_err*("Incompatible_magnification_"); *print_int*(*mag*); *print*("");
 print_nl("the_previous_value_will_be_retained");
 help2("I_can_handle_only_one_magnification_ratio_per_job._So_I've")
 ("reverted_to_the_magnification_you_used_earlier_on_this_run.");
 int_error(*mag_set*); *geq_word_define*(*int_base* + *mag_code*, *mag_set*); { *mag* \leftarrow *mag_set* }
 end;
if (*mag* \leq 0) \vee (*mag* > 32768) **then**
 begin *print_err*("Illegal_magnification_has_been_changed_to_1000");
 help1("The_magnification_ratio_must_be_between_1_and_32768."); *int_error*(*mag*);
 geq_word_define(*int_base* + *mag_code*, 1000);
 end;
 mag_set \leftarrow *mag*;
end;

311. Token lists. A \TeX token is either a character or a control sequence, and it is represented internally in one of two ways: (1) A character whose ASCII code number is c and whose command code is m is represented as the number $2^8m + c$; the command code is in the range $1 \leq m \leq 14$. (2) A control sequence whose *eqtb* address is p is represented as the number $cs_token_flag + p$. Here $cs_token_flag = 2^{12} - 1$ is larger than $2^8m + c$, yet it is small enough that $cs_token_flag + p < max_halfword$; thus, a token fits comfortably in a halfword.

A token t represents a *left_brace* command if and only if $t < left_brace_limit$; it represents a *right_brace* command if and only if we have $left_brace_limit \leq t < right_brace_limit$; and it represents a *match* or *end_match* command if and only if $match_token \leq t \leq end_match_token$. The following definitions take care of these token-oriented constants and a few others.

```

define cs_token_flag  $\equiv$  '7777 { amount added to the eqtb location in a token that stands for a control
sequence; is a multiple of 256, less 1 }
define left_brace_token = '0400 {  $2^8 \cdot left\_brace$  }
define left_brace_limit = '1000 {  $2^8 \cdot (left\_brace + 1)$  }
define right_brace_token = '1000 {  $2^8 \cdot right\_brace$  }
define right_brace_limit = '1400 {  $2^8 \cdot (right\_brace + 1)$  }
define math_shift_token = '1400 {  $2^8 \cdot math\_shift$  }
define tab_token = '2000 {  $2^8 \cdot tab\_mark$  }
define out_param_token = '2400 {  $2^8 \cdot out\_param$  }
define space_token = '5040 {  $2^8 \cdot spacer + "\_"$  }
define letter_token = '5400 {  $2^8 \cdot letter$  }
define other_token = '6000 {  $2^8 \cdot other\_char$  }
define match_token = '6400 {  $2^8 \cdot match$  }
define end_match_token = '7000 {  $2^8 \cdot end\_match$  }
define protected_token = '7001 {  $2^8 \cdot end\_match + 1$  }

```

312. \langle Check the “constant” values for consistency 14 $\rangle + \equiv$

```

if cs_token_flag + undefined_control_sequence > max_halfword then bad  $\leftarrow$  21;

```

313. A token list is a singly linked list of one-word nodes in *mem*, where each word contains a token and a link. Macro definitions, output-routine definitions, marks, `\write` texts, and a few other things are remembered by TeX in the form of token lists, usually preceded by a node with a reference count in its *token_ref_count* field. The token stored in location *p* is called *info(p)*.

Three special commands appear in the token lists of macro definitions. When *m* = *match*, it means that TeX should scan a parameter for the current macro; when *m* = *end_match*, it means that parameter matching should end and TeX should start reading the macro text; and when *m* = *out_param*, it means that TeX should insert parameter number *c* into the text at this point.

The enclosing { and } characters of a macro definition are omitted, but an output routine will be enclosed in braces.

Here is an example macro definition that illustrates these conventions. After TeX processes the text

```
\def\mac a#1#2 \b {#1\ -a ##1#2 #2}
```

the definition of `\mac` is represented as a token list containing

```
(reference count), letter a, match #, match #, spacer ␣, \b, end_match,
out_param 1, \ -, letter a, spacer ␣, mac_param #, other_char 1,
out_param 2, spacer ␣, out_param 2.
```

The procedure *scan_toks* builds such token lists, and *macro_call* does the parameter matching.

Examples such as

```
\def\m{\def\m{a}␣b}
```

explain why reference counts would be needed even if TeX had no `\let` operation: When the token list for `\m` is being read, the redefinition of `\m` changes the *eqtb* entry before the token list has been fully consumed, so we dare not simply destroy a token list when its control sequence is being redefined.

If the parameter-matching part of a definition ends with `#{`, the corresponding token list will have `{` just before the *end_match* and also at the very end. The first `{` is used to delimit the parameter; the second one keeps the first from disappearing.

314. The procedure *show_token_list*, which prints a symbolic form of the token list that starts at a given node *p*, illustrates these conventions. The token list being displayed should not begin with a reference count. However, the procedure is intended to be robust, so that if the memory links are awry or if *p* is not really a pointer to a token list, nothing catastrophic will happen.

An additional parameter *q* is also given; this parameter is either null or it points to a node in the token list where a certain magic computation takes place that will be explained later. (Basically, *q* is non-null when we are printing the two-line context information at the time of an error message; *q* marks the place corresponding to where the second line should begin.)

For example, if *p* points to the node containing the first **a** in the token list above, then *show_token_list* will print the string

‘a#1#2␣b␣->#1\ -a␣##1#2␣#2’;

and if *q* points to the node containing the second **a**, the magic computation will be performed just before the second **a** is printed.

The generation will stop, and ‘ETC.’ will be printed, if the length of printing exceeds a given limit *l*. Anomalous entries are printed in the form of control sequences that are not followed by a blank space, e.g., ‘\BAD.’; this cannot be confused with actual control sequences because a real control sequence named **BAD** would come out ‘\BAD␣’.

⟨Declare the procedure called *show_token_list* 314⟩ ≡

```
procedure show_token_list(p, q : integer; l : integer);
  label exit;
  var m, c : integer; { pieces of a token }
      match_chr : ASCII_code; { character used in a ‘match’ }
      n : ASCII_code; { the highest parameter number, as an ASCII digit }
  begin match_chr ← “#”; n ← “0”; tally ← 0;
  while (p ≠ null) ∧ (tally < l) do
    begin if p = q then ⟨Do magic computation 342⟩;
      ⟨Display token p, and return if there are problems 315⟩;
      p ← link(p);
    end;
    if p ≠ null then print_esc(“ETC.”);
  exit : end;
```

This code is used in section 137.

315. ⟨Display token *p*, and **return** if there are problems 315⟩ ≡

```
if (p < hi_mem_min) ∨ (p > mem_end) then
  begin print_esc(“CLOBBED.”); return;
end;
if info(p) ≥ cs_token_flag then print_cs(info(p) − cs_token_flag)
else begin m ← info(p) div ‘400; c ← info(p) mod ‘400;
  if info(p) < 0 then print_esc(“BAD.”)
  else ⟨Display the token (m, c) 316⟩;
end
```

This code is used in section 314.

316. The procedure usually “learns” the character code used for macro parameters by seeing one in a *match* command before it runs into any *out_param* commands.

```

⟨Display the token (m, c) 316⟩ ≡
  case m of
    left_brace, right_brace, math_shift, tab_mark, sup_mark, sub_mark, spacer, letter, other_char: print(c);
    mac_param: begin print(c); print(c);
                end;
    out_param: begin print(match_chr);
                if c ≤ 9 then print_char(c + "0")
                else begin print_char("!"); return;
                end;
                end;
    match: begin match_chr ← c; print(c); incr(n); print_char(n);
            if n > "9" then return;
            end;
    end_match: if c = 0 then print("->");
               othercases print_esc("BAD.");
    endcases
endcases

```

This code is used in section 315.

317. Here’s the way we sometimes want to display a token list, given a pointer to its reference count; the pointer may be null.

```

procedure token_show(p : pointer);
  begin if p ≠ null then show_token_list(link(p), null, 10000000);
  end;

```

318. The *print_meaning* subroutine displays *cur_cmd* and *cur_chr* in symbolic form, including the expansion of a macro or mark.

```

procedure print_meaning;
  begin print_cmd_chr(cur_cmd, cur_chr);
  if cur_cmd ≥ call then
    begin print_char(":"); print_ln; token_show(cur_chr);
    end
  else if (cur_cmd = top_bot_mark) ∧ (cur_chr < marks_code) then
    begin print_char(":"); print_ln; token_show(cur_mark[cur_chr]);
    end;
  end;

```

319. Introduction to the syntactic routines. Let's pause a moment now and try to look at the Big Picture. The T_EX program consists of three main parts: syntactic routines, semantic routines, and output routines. The chief purpose of the syntactic routines is to deliver the user's input to the semantic routines, one token at a time. The semantic routines act as an interpreter responding to these tokens, which may be regarded as commands. And the output routines are periodically called on to convert box-and-glue lists into a compact set of instructions that will be sent to a typesetter. We have discussed the basic data structures and utility routines of T_EX, so we are good and ready to plunge into the real activity by considering the syntactic routines.

Our current goal is to come to grips with the *get_next* procedure, which is the keystone of T_EX's input mechanism. Each call of *get_next* sets the value of three variables *cur_cmd*, *cur_chr*, and *cur_cs*, representing the next input token.

cur_cmd denotes a command code from the long list of codes given above;
cur_chr denotes a character code or other modifier of the command code;
cur_cs is the *eqtb* location of the current control sequence,
 if the current token was a control sequence, otherwise it's zero.

Underlying this external behavior of *get_next* is all the machinery necessary to convert from character files to tokens. At a given time we may be only partially finished with the reading of several files (for which `\input` was specified), and partially finished with the expansion of some user-defined macros and/or some macro parameters, and partially finished with the generation of some text in a template for `\halign`, and so on. When reading a character file, special characters must be classified as math delimiters, etc.; comments and extra blank spaces must be removed, paragraphs must be recognized, and control sequences must be found in the hash table. Furthermore there are occasions in which the scanning routines have looked ahead for a word like 'plus' but only part of that word was found, hence a few characters must be put back into the input and scanned again.

To handle these situations, which might all be present simultaneously, T_EX uses various stacks that hold information about the incomplete activities, and there is a finite state control for each level of the input mechanism. These stacks record the current state of an implicitly recursive process, but the *get_next* procedure is not recursive. Therefore it will not be difficult to translate these algorithms into low-level languages that do not support recursion.

⟨Global variables 13⟩ +≡

cur_cmd: *eight_bits*; { current command set by *get_next* }

cur_chr: *halfword*; { operand of current command }

cur_cs: *pointer*; { control sequence found here, zero if none found }

cur_tok: *halfword*; { packed representative of *cur_cmd* and *cur_chr* }

320. The *print_cmd_chr* routine prints a symbolic interpretation of a command code and its modifier. This is used in certain ‘You can’t’ error messages, and in the implementation of diagnostic routines like `\show`.

The body of *print_cmd_chr* is a rather tedious listing of print commands, and most of it is essentially an inverse to the *primitive* routine that enters a TeX primitive into *eqtb*. Therefore much of this procedure appears elsewhere in the program, together with the corresponding *primitive* calls.

```

define chr_cmd(#) ≡
    begin print(#); print_ASCII(chr_code);
    end

⟨ Declare the procedure called print_cmd_chr 320 ⟩ ≡
procedure print_cmd_chr(cmd : quarterword; chr_code : halfword);
    var n: integer; { temp variable }
    begin case cmd of
        left_brace: chr_cmd("begin-group_character_");
        right_brace: chr_cmd("end-group_character_");
        math_shift: chr_cmd("math_shift_character_");
        mac_param: chr_cmd("macro_parameter_character_");
        sup_mark: chr_cmd("superscript_character_");
        sub_mark: chr_cmd("subscript_character_");
        endv: print("end_of_alignment_template");
        spacer: chr_cmd("blank_space_");
        letter: chr_cmd("the_letter_");
        other_char: chr_cmd("the_character_");
        ⟨ Cases of print_cmd_chr for symbolic printing of primitives 245 ⟩
        othercases print("[unknown_command_code!]")
    endcases;
    end;

```

This code is used in section 270.

321. Here is a procedure that displays the current command.

```

procedure show_cur_cmd_chr;
  var n: integer; { level of \if... \fi nesting }
      l: integer; { line where \if started }
      p: pointer;
  begin begin_diagnostic; print_nl("{");
  if mode  $\neq$  shown_mode then
    begin print_mode(mode); print(":␣"); shown_mode  $\leftarrow$  mode;
    end;
  print_cmd_chr(cur_cmd, cur_chr);
  if tracing_ifs > 0 then
    if cur_cmd  $\geq$  if_test then
      if cur_cmd  $\leq$  fi_or_else then
        begin print(":␣");
        if cur_cmd = fi_or_else then
          begin print_cmd_chr(if_test, cur_if); print_char("␣"); n  $\leftarrow$  0; l  $\leftarrow$  if_line;
          end
        else begin n  $\leftarrow$  1; l  $\leftarrow$  line;
        end;
      p  $\leftarrow$  cond_ptr;
      while p  $\neq$  null do
        begin incr(n); p  $\leftarrow$  link(p);
        end;
        print("(level␣"); print_int(n); print_char(""); print_if_line(l);
        end;
      print_char("}"); end_diagnostic(false);
    end;

```

322. Input stacks and states. This implementation of T_EX uses two different conventions for representing sequential stacks.

- 1) If there is frequent access to the top entry, and if the stack is essentially never empty, then the top entry is kept in a global variable (even better would be a machine register), and the other entries appear in the array *stack*[0 .. (*ptr* − 1)]. For example, the semantic stack described above is handled this way, and so is the input stack that we are about to study.
- 2) If there is infrequent top access, the entire stack contents are in the array *stack*[0 .. (*ptr* − 1)]. For example, the *save_stack* is treated this way, as we have seen.

The state of T_EX’s input mechanism appears in the input stack, whose entries are records with six fields, called *state*, *index*, *start*, *loc*, *limit*, and *name*. This stack is maintained with convention (1), so it is declared in the following way:

```
⟨Types in the outer block 18⟩ +≡
  in_state_record = record state_field, index_field: quarterword;
                    start_field, loc_field, limit_field, name_field: halfword;
                    end;
```

323. ⟨Global variables 13⟩ +≡
input_stack: **array** [0 .. *stack_size*] **of** *in_state_record*;
input_ptr: 0 .. *stack_size*; { first unused location of *input_stack* }
max_in_stack: 0 .. *stack_size*; { largest value of *input_ptr* when pushing }
cur_input: *in_state_record*; { the “top” input state, according to convention (1) }

324. We’ve already defined the special variable *loc* ≡ *cur_input.loc_field* in our discussion of basic input-output routines. The other components of *cur_input* are defined in the same way:

```
define state ≡ cur_input.state_field { current scanner state }
define index ≡ cur_input.index_field { reference for buffer information }
define start ≡ cur_input.start_field { starting position in buffer }
define limit ≡ cur_input.limit_field { end of current line in buffer }
define name ≡ cur_input.name_field { name of the current file }
```

325. Let's look more closely now at the control variables (*state*, *index*, *start*, *loc*, *limit*, *name*), assuming that TeX is reading a line of characters that have been input from some file or from the user's terminal. There is an array called *buffer* that acts as a stack of all lines of characters that are currently being read from files, including all lines on subsidiary levels of the input stack that are not yet completed. TeX will return to the other lines when it is finished with the present input file.

(Incidentally, on a machine with byte-oriented addressing, it might be appropriate to combine *buffer* with the *str_pool* array, letting the buffer entries grow downward from the top of the string pool and checking that these two tables don't bump into each other.)

The line we are currently working on begins in position *start* of the buffer; the next character we are about to read is *buffer[loc]*; and *limit* is the location of the last character present. If *loc* > *limit*, the line has been completely read. Usually *buffer[limit]* is the *end_line_char*, denoting the end of a line, but this is not true if the current line is an insertion that was entered on the user's terminal in response to an error message.

The *name* variable is a string number that designates the name of the current file, if we are reading a text file. It is zero if we are reading from the terminal; it is $n + 1$ if we are reading from input stream n , where $0 \leq n \leq 16$. (Input stream 16 stands for an invalid stream number; in such cases the input is actually from the terminal, under control of the procedure *read_toks*.) Finally $18 \leq name \leq 19$ indicates that we are reading a pseudo file created by the `\scantokens` command.

The *state* variable has one of three values, when we are scanning such files:

- 1) *state* = *mid_line* is the normal state.
- 2) *state* = *skip_blanks* is like *mid_line*, but blanks are ignored.
- 3) *state* = *new_line* is the state at the beginning of a line.

These state values are assigned numeric codes so that if we add the state code to the next character's command code, we get distinct values. For example, '*mid_line* + *spacer*' stands for the case that a blank space character occurs in the middle of a line when it is not being ignored; after this case is processed, the next value of *state* will be *skip_blanks*.

```
define mid_line = 1 { state code when scanning a line of characters }
define skip_blanks = 2 + max_char_code { state code when ignoring blanks }
define new_line = 3 + max_char_code + max_char_code { state code at start of line }
```

326. Additional information about the current line is available via the *index* variable, which counts how many lines of characters are present in the buffer below the current level. We have *index* = 0 when reading from the terminal and prompting the user for each line; then if the user types, e.g., ‘\input paper’, we will have *index* = 1 while reading the file `paper.tex`. However, it does not follow that *index* is the same as the input stack pointer, since many of the levels on the input stack may come from token lists. For example, the instruction ‘\input paper’ might occur in a token list.

The global variable *in_open* is equal to the *index* value of the highest non-token-list level. Thus, the number of partially read lines in the buffer is *in_open* + 1, and we have *in_open* = *index* when we are not reading a token list.

If we are not currently reading from the terminal, or from an input stream, we are reading from the file variable *input_file*[*index*]. We use the notation *terminal_input* as a convenient abbreviation for *name* = 0, and *cur_file* as an abbreviation for *input_file*[*index*].

The global variable *line* contains the line number in the topmost open file, for use in error messages. If we are not reading from the terminal, *line_stack*[*index*] holds the line number for the enclosing level, so that *line* can be restored when the current file has been read. Line numbers should never be negative, since the negative of the current line number is used to identify the user’s output routine in the *mode_line* field of the semantic nest entries.

If more information about the input state is needed, it can be included in small arrays like those shown here. For example, the current page or segment number in the input file might be put into a variable *page*, maintained for enclosing levels in ‘*page_stack*: **array** [1 .. *max_in_open*] **of** *integer*’ by analogy with *line_stack*.

define *terminal_input* \equiv (*name* = 0) { are we reading from the terminal? }

define *cur_file* \equiv *input_file*[*index*] { the current *alpha_file* variable }

⟨ Global variables 13 ⟩ +≡

in_open: 0 .. *max_in_open*; { the number of lines in the buffer, less one }

open_parens: 0 .. *max_in_open*; { the number of open text files }

input_file: **array** [1 .. *max_in_open*] **of** *alpha_file*;

line: *integer*; { current line number in the current source file }

line_stack: **array** [1 .. *max_in_open*] **of** *integer*;

327. Users of T_EX sometimes forget to balance left and right braces properly, and one of the ways T_EX tries to spot such errors is by considering an input file as broken into subfiles by control sequences that are declared to be `\outer`.

A variable called *scanner_status* tells T_EX whether or not to complain when a subfile ends. This variable has six possible values:

normal, means that a subfile can safely end here without incident.

skipping, means that a subfile can safely end here, but not a file, because we're reading past some conditional text that was not selected.

defining, means that a subfile shouldn't end now because a macro is being defined.

matching, means that a subfile shouldn't end now because a macro is being used and we are searching for the end of its arguments.

aligning, means that a subfile shouldn't end now because we are not finished with the preamble of an `\halign` or `\valign`.

absorbing, means that a subfile shouldn't end now because we are reading a balanced token list for `\message`, `\write`, etc.

If the *scanner_status* is not *normal*, the variable *warning_index* points to the *eqtb* location for the relevant control sequence name to print in an error message.

```
define skipping = 1 { scanner_status when passing conditional text }
define defining = 2 { scanner_status when reading a macro definition }
define matching = 3 { scanner_status when reading macro arguments }
define aligning = 4 { scanner_status when reading an alignment preamble }
define absorbing = 5 { scanner_status when reading a balanced text }
```

⟨Global variables 13⟩ +≡

scanner_status: *normal* .. *absorbing*; { can a subfile end now? }

warning_index: *pointer*; { identifier relevant to non-*normal* scanner status }

def_ref: *pointer*; { reference count of token list being defined }

328. Here is a procedure that uses *scanner_status* to print a warning message when a subfile has ended, and at certain other crucial times:

⟨Declare the procedure called *runaway* 328⟩ ≡

procedure *runaway*;

var *p*: *pointer*; { head of runaway list }

begin if *scanner_status* > *skipping* **then**

begin *print_nl*("Runaway␣");

case *scanner_status* **of**

defining: **begin** *print*("definition"); *p* ← *def_ref*;

end;

matching: **begin** *print*("argument"); *p* ← *temp_head*;

end;

aligning: **begin** *print*("preamble"); *p* ← *hold_head*;

end;

absorbing: **begin** *print*("text"); *p* ← *def_ref*;

end;

end; { there are no other cases }

print_char("?"); *print_ln*; *show_token_list*(*link*(*p*), *null*, *error_line* − 10);

end;

end;

This code is used in section 137.

329. However, all this discussion about input state really applies only to the case that we are inputting from a file. There is another important case, namely when we are currently getting input from a token list. In this case *state* = *token_list*, and the conventions about the other state variables are different:

loc is a pointer to the current node in the token list, i.e., the node that will be read next. If *loc* = *null*, the token list has been fully read.

start points to the first node of the token list; this node may or may not contain a reference count, depending on the type of token list involved.

token_type, which takes the place of *index* in the discussion above, is a code number that explains what kind of token list is being scanned.

name points to the *eqtb* address of the control sequence being expanded, if the current token list is a macro.

param_start, which takes the place of *limit*, tells where the parameters of the current macro begin in the *param_stack*, if the current token list is a macro.

The *token_type* can take several values, depending on where the current token list came from:

parameter, if a parameter is being scanned;

u_template, if the $\langle u_j \rangle$ part of an alignment template is being scanned;

v_template, if the $\langle v_j \rangle$ part of an alignment template is being scanned;

backed_up, if the token list being scanned has been inserted as ‘to be read again’;

inserted, if the token list being scanned has been inserted as the text expansion of a `\count` or similar variable;

macro, if a user-defined control sequence is being scanned;

output_text, if an `\output` routine is being scanned;

every_par_text, if the text of `\everypar` is being scanned;

every_math_text, if the text of `\everymath` is being scanned;

every_display_text, if the text of `\everydisplay` is being scanned;

every_hbox_text, if the text of `\everyhbox` is being scanned;

every_vbox_text, if the text of `\everyvbox` is being scanned;

every_job_text, if the text of `\everyjob` is being scanned;

every_cr_text, if the text of `\everycr` is being scanned;

mark_text, if the text of a `\mark` is being scanned;

write_text, if the text of a `\write` is being scanned.

The codes for *output_text*, *every_par_text*, etc., are equal to a constant plus the corresponding codes for token list parameters *output_routine_loc*, *every_par_loc*, etc. The token list begins with a reference count if and only if *token_type* \geq *macro*.

Since ε -TeX’s additional token list parameters precede *toks_base*, the corresponding token types must precede *write_text*.

```

define token_list = 0 { state code when scanning a token list }
define token_type  $\equiv$  index { type of current token list }
define param_start  $\equiv$  limit { base of macro parameters in param_stack }
define parameter = 0 { token_type code for parameter }
define u_template = 1 { token_type code for  $\langle u_j \rangle$  template }
define v_template = 2 { token_type code for  $\langle v_j \rangle$  template }
define backed_up = 3 { token_type code for text to be reread }
define inserted = 4 { token_type code for inserted texts }
define macro = 5 { token_type code for defined control sequences }
define output_text = 6 { token_type code for output routines }
define every_par_text = 7 { token_type code for \everypar }
define every_math_text = 8 { token_type code for \everymath }
define every_display_text = 9 { token_type code for \everydisplay }
define every_hbox_text = 10 { token_type code for \everyhbox }
define every_vbox_text = 11 { token_type code for \everyvbox }

```

```

define every_job_text = 12 { token_type code for \everyjob }
define every_cr_text = 13 { token_type code for \everycr }
define mark_text = 14 { token_type code for \topmark, etc. }
define eTeX_text_offset = output_routine_loc - output_text
define every_eof_text = every_eof_loc - eTeX_text_offset { token_type code for \everyeof }
define write_text = toks_base - eTeX_text_offset { token_type code for \write }

```

330. The *param_stack* is an auxiliary array used to hold pointers to the token lists for parameters at the current level and subsidiary levels of input. This stack is maintained with convention (2), and it grows at a different rate from the others.

```

⟨Global variables 13⟩ +≡
param_stack: array [0..param_size] of pointer; { token list pointers for parameters }
param_ptr: 0..param_size; { first unused entry in param_stack }
max_param_stack: integer; { largest value of param_ptr, will be  $\leq$  param_size + 9 }

```

331. The input routines must also interact with the processing of `\halign` and `\valign`, since the appearance of tab marks and `\cr` in certain places is supposed to trigger the beginning of special $\langle v_j \rangle$ template text in the scanner. This magic is accomplished by an *align_state* variable that is increased by 1 when a ‘{’ is scanned and decreased by 1 when a ‘}’ is scanned. The *align_state* is nonzero during the $\langle u_j \rangle$ template, after which it is set to zero; the $\langle v_j \rangle$ template begins when a tab mark or `\cr` occurs at a time that *align_state* = 0.

```

⟨Global variables 13⟩ +≡
align_state: integer; { group level with respect to current alignment }

```

332. Thus, the “current input state” can be very complicated indeed; there can be many levels and each level can arise in a variety of ways. The *show_context* procedure, which is used by TeX’s error-reporting routine to print out the current input state on all levels down to the most recent line of characters from an input file, illustrates most of these conventions. The global variable *base_ptr* contains the lowest level that was displayed by this procedure.

```

⟨Global variables 13⟩ +≡
base_ptr: 0..stack_size; { shallowest level shown by show_context }

```

333. The status at each level is indicated by printing two lines, where the first line indicates what was read so far and the second line shows what remains to be read. The context is cropped, if necessary, so that the first line contains at most *half_error_line* characters, and the second contains at most *error_line*. Non-current input levels whose *token_type* is ‘*backed-up*’ are shown only if they have not been fully read.

```
procedure show_context; { prints where the scanner is }
label done;
var old_setting: 0 .. max_selector; { saved selector setting }
    nn: integer; { number of contexts shown so far, less one }
    bottom_line: boolean; { have we reached the final context to be shown? }
    <Local variables for formatting calculations 337>
begin base_ptr ← input_ptr; input_stack[base_ptr] ← cur_input; { store current state }
    nn ← -1; bottom_line ← false;
loop begin cur_input ← input_stack[base_ptr]; { enter into the context }
    if (state ≠ token_list) then
        if (name > 19) ∨ (base_ptr = 0) then bottom_line ← true;
    if (base_ptr = input_ptr) ∨ bottom_line ∨ (nn < error_context_lines) then
        <Display the current context 334>
    else if nn = error_context_lines then
        begin print_nl("..."); incr(nn); { omitted if error_context_lines < 0 }
        end;
    if bottom_line then goto done;
    decr(base_ptr);
end;
done: cur_input ← input_stack[input_ptr]; { restore original state }
end;
```

```
334. <Display the current context 334> ≡
begin if (base_ptr = input_ptr) ∨ (state ≠ token_list) ∨ (token_type ≠ backed_up) ∨ (loc ≠ null) then
    { we omit backed-up token lists that have already been read }
    begin tally ← 0; { get ready to count characters }
    old_setting ← selector;
    if state ≠ token_list then
        begin <Print location of current line 335>;
        <Pseudoprint the line 340>;
        end
    else begin <Print type of token list 336>;
        <Pseudoprint the token list 341>;
        end;
    selector ← old_setting; { stop pseudoprinting }
    <Print two lines using the tricky pseudoprinted information 339>;
    incr(nn);
end;
end
```

This code is used in section 333.

335. This routine should be changed, if necessary, to give the best possible indication of where the current line resides in the input file. For example, on some systems it is best to print both a page and line number.

⟨Print location of current line 335⟩ ≡

```

if name ≤ 17 then
  if terminal_input then
    if base_ptr = 0 then print_nl("<*>")
    else print_nl("<insert>␣")
  else begin print_nl("<read␣");
    if name = 17 then print_char("*") else print_int(name − 1);
    print_char(">");
  end
else if index ≠ in_open then { input from a pseudo file }
  begin print_nl("1."); print_int(line_stack[index + 1]);
  end
else begin print_nl("1."); print_int(line);
  end;
print_char("␣")

```

This code is used in section 334.

336. ⟨Print type of token list 336⟩ ≡

```

case token_type of
  parameter: print_nl("<argument>␣");
  u_template, v_template: print_nl("<template>␣");
  backed_up: if loc = null then print_nl("<recently␣read>␣")
    else print_nl("<to␣be␣read␣again>␣");
  inserted: print_nl("<inserted␣text>␣");
  macro: begin print_ln; print_cs(name);
  end;
  output_text: print_nl("<output>␣");
  every_par_text: print_nl("<everypar>␣");
  every_math_text: print_nl("<everymath>␣");
  every_display_text: print_nl("<everydisplay>␣");
  every_hbox_text: print_nl("<everyhbox>␣");
  every_vbox_text: print_nl("<everyvbox>␣");
  every_job_text: print_nl("<everyjob>␣");
  every_cr_text: print_nl("<everycr>␣");
  mark_text: print_nl("<mark>␣");
  every_eof_text: print_nl("<everyeof>␣");
  write_text: print_nl("<write>␣");
  othercases print_nl("?") { this should never happen }
endcases

```

This code is used in section 334.

337. Here it is necessary to explain a little trick. We don't want to store a long string that corresponds to a token list, because that string might take up lots of memory; and we are printing during a time when an error message is being given, so we dare not do anything that might overflow one of TeX's tables. So 'pseudoprinting' is the answer: We enter a mode of printing that stores characters into a buffer of length *error_line*, where character $k + 1$ is placed into *trick_buf*[$k \bmod \text{error_line}$] if $k < \text{trick_count}$, otherwise character k is dropped. Initially we set *tally* $\leftarrow 0$ and *trick_count* $\leftarrow 1000000$; then when we reach the point where transition from line 1 to line 2 should occur, we set *first_count* $\leftarrow \text{tally}$ and *trick_count* $\leftarrow \max(\text{error_line}, \text{tally} + 1 + \text{error_line} - \text{half_error_line})$. At the end of the pseudoprinting, the values of *first_count*, *tally*, and *trick_count* give us all the information we need to print the two lines, and all of the necessary text is in *trick_buf*.

Namely, let l be the length of the descriptive information that appears on the first line. The length of the context information gathered for that line is $k = \text{first_count}$, and the length of the context information gathered for line 2 is $m = \min(\text{tally}, \text{trick_count}) - k$. If $l + k \leq h$, where $h = \text{half_error_line}$, we print *trick_buf*[$0 \dots k - 1$] after the descriptive information on line 1, and set $n \leftarrow l + k$; here n is the length of line 1. If $l + k > h$, some cropping is necessary, so we set $n \leftarrow h$ and print '...' followed by

$$\text{trick_buf}[(l + k - h + 3) \dots k - 1],$$

where subscripts of *trick_buf* are circular modulo *error_line*. The second line consists of n spaces followed by *trick_buf*[$k \dots (k + m - 1)$], unless $n + m > \text{error_line}$; in the latter case, further cropping is done. This is easier to program than to explain.

<Local variables for formatting calculations 337> \equiv
i: $0 \dots \text{buf_size}$; {index into *buffer*}
j: $0 \dots \text{buf_size}$; {end of current line in *buffer*}
l: $0 \dots \text{half_error_line}$; {length of descriptive information on line 1}
m: *integer*; {context information gathered for line 2}
n: $0 \dots \text{error_line}$; {length of line 1}
p: *integer*; {starting or ending place in *trick_buf*}
q: *integer*; {temporary index}

This code is used in section 333.

338. The following code sets up the print routines so that they will gather the desired information.

```

define begin_pseudoprint  $\equiv$ 
    begin l  $\leftarrow \text{tally}$ ; tally  $\leftarrow 0$ ; selector  $\leftarrow \text{pseudo}$ ; trick_count  $\leftarrow 1000000$ ;
    end
define set_trick_count  $\equiv$ 
    begin first_count  $\leftarrow \text{tally}$ ; trick_count  $\leftarrow \text{tally} + 1 + \text{error\_line} - \text{half\_error\_line}$ ;
    if trick_count  $< \text{error\_line}$  then trick_count  $\leftarrow \text{error\_line}$ ;
    end
```

339. And the following code uses the information after it has been gathered.

```

⟨Print two lines using the tricky pseudoprinted information 339⟩ ≡
  if trick_count = 1000000 then set_trick_count; { set_trick_count must be performed }
  if tally < trick_count then m ← tally − first_count
  else m ← trick_count − first_count; { context on line 2 }
  if l + first_count ≤ half_error_line then
    begin p ← 0; n ← l + first_count;
    end
  else begin print("..."); p ← l + first_count − half_error_line + 3; n ← half_error_line;
    end;
  for q ← p to first_count − 1 do print_char(trick_buf[q mod error_line]);
  print_ln;
  for q ← 1 to n do print_char(" "); { print n spaces to begin line 2 }
  if m + n ≤ error_line then p ← first_count + m
  else p ← first_count + (error_line − n − 3);
  for q ← first_count to p − 1 do print_char(trick_buf[q mod error_line]);
  if m + n > error_line then print("...")

```

This code is used in section 334.

340. But the trick is distracting us from our current goal, which is to understand the input state. So let's concentrate on the data structures that are being pseudoprinted as we finish up the *show_context* procedure.

```

⟨Pseudoprint the line 340⟩ ≡
  begin_pseudoprint;
  if buffer[limit] = end_line_char then j ← limit
  else j ← limit + 1; { determine the effective end of the line }
  if j > 0 then
    for i ← start to j − 1 do
      begin if i = loc then set_trick_count;
      print(buffer[i]);
      end
  end

```

This code is used in section 334.

```

341. ⟨Pseudoprint the token list 341⟩ ≡
  begin_pseudoprint;
  if token_type < macro then show_token_list(start, loc, 100000)
  else show_token_list(link(start), loc, 100000) { avoid reference count }

```

This code is used in section 334.

342. Here is the missing piece of *show_token_list* that is activated when the token beginning line 2 is about to be shown:

```

⟨Do magic computation 342⟩ ≡
  set_trick_count

```

This code is used in section 314.

343. Maintaining the input stacks. The following subroutines change the input status in commonly needed ways.

First comes *push_input*, which stores the current state and creates a new level (having, initially, the same properties as the old).

```

define push_input  $\equiv$  { enter a new input level, save the old }
  begin if input_ptr > max_in_stack then
    begin max_in_stack  $\leftarrow$  input_ptr;
    if input_ptr = stack_size then overflow("input_stack_size", stack_size);
    end;
    input_stack[input_ptr]  $\leftarrow$  cur_input; { stack the record }
    incr(input_ptr);
  end

```

344. And of course what goes up must come down.

```

define pop_input  $\equiv$  { leave an input level, re-enter the old }
  begin decr(input_ptr); cur_input  $\leftarrow$  input_stack[input_ptr];
  end

```

345. Here is a procedure that starts a new level of token-list input, given a token list *p* and its type *t*. If *t* = *macro*, the calling routine should set *name* and *loc*.

```

define back_list(#)  $\equiv$  begin_token_list(#, backed_up) { backs up a simple token list }
define ins_list(#)  $\equiv$  begin_token_list(#, inserted) { inserts a simple token list }
procedure begin_token_list(p : pointer; t : quarterword);
  begin push_input; state  $\leftarrow$  token_list; start  $\leftarrow$  p; token_type  $\leftarrow$  t;
  if t  $\geq$  macro then { the token list starts with a reference count }
    begin add_token_ref(p);
    if t = macro then param_start  $\leftarrow$  param_ptr
  else begin loc  $\leftarrow$  link(p);
    if tracing_macros > 1 then
      begin begin_diagnostic; print_nl("");
      case t of
        mark_text: print_esc("mark");
        write_text: print_esc("write");
        othercases print_cmd_chr(assign_toks, t - output_text + output_routine_loc)
      endcases;
      print("->"); token_show(p); end_diagnostic(false);
    end;
  end;
end
end
else loc  $\leftarrow$  p;
end;

```

346. When a token list has been fully scanned, the following computations should be done as we leave that level of input. The *token_type* tends to be equal to either *backed_up* or *inserted* about 2/3 of the time.

```
procedure end_token_list; { leave a token-list input level }
begin if token_type ≥ backed_up then { token list to be deleted }
  begin if token_type ≤ inserted then flush_list(start)
  else begin delete_token_ref(start); { update reference count }
    if token_type = macro then { parameters must be flushed }
      while param_ptr > param_start do
        begin decr(param_ptr); flush_list(param_stack[param_ptr]);
        end;
      end;
    end;
  end
else if token_type = u_template then
  if align_state > 500000 then align_state ← 0
  else fatal_error("(interwoven_alignment_preambles_are_not_allowed)");
pop_input; check_interrupt;
end;
```

347. Sometimes T_EX has read too far and wants to “unscan” what it has seen. The *back_input* procedure takes care of this by putting the token just scanned back into the input stream, ready to be read again. This procedure can be used only if *cur_tok* represents the token to be replaced. Some applications of T_EX use this procedure a lot, so it has been slightly optimized for speed.

```
procedure back_input; { undoes one token of input }
var p: pointer; { a token list of length one }
begin while (state = token_list) ∧ (loc = null) ∧ (token_type ≠ v_template) do end_token_list;
  { conserve stack space }
p ← get_avail; info(p) ← cur_tok;
if cur_tok < right_brace_limit then
  if cur_tok < left_brace_limit then decr(align_state)
  else incr(align_state);
push_input; state ← token_list; start ← p; token_type ← backed_up; loc ← p;
  { that was back_list(p), without procedure overhead }
end;
```

348. ⟨ Insert token *p* into T_EX’s input 348 ⟩ ≡

```
begin t ← cur_tok; cur_tok ← p;
if a then
  begin p ← get_avail; info(p) ← cur_tok; link(p) ← loc; loc ← p; start ← p;
  if cur_tok < right_brace_limit then
    if cur_tok < left_brace_limit then decr(align_state)
    else incr(align_state);
  end
else begin back_input; a ← eTeX_ex;
  end;
cur_tok ← t;
end
```

This code is used in section 304.

349. The *back_error* routine is used when we want to replace an offending token just before issuing an error message. This routine, like *back_input*, requires that *cur_tok* has been set. We disable interrupts during the call of *back_input* so that the help message won't be lost.

```
procedure back_error; { back up one token and call error }
  begin OK_to_interrupt  $\leftarrow$  false; back_input; OK_to_interrupt  $\leftarrow$  true; error;
  end;

procedure ins_error; { back up one inserted token and call error }
  begin OK_to_interrupt  $\leftarrow$  false; back_input; token_type  $\leftarrow$  inserted; OK_to_interrupt  $\leftarrow$  true; error;
  end;
```

350. The *begin_file_reading* procedure starts a new level of input for lines of characters to be read from a file, or as an insertion from the terminal. It does not take care of opening the file, nor does it set *loc* or *limit* or *line*.

```
procedure begin_file_reading;
  begin if in_open = max_in_open then overflow("text_input_levels", max_in_open);
  if first = buf_size then overflow("buffer_size", buf_size);
  incr(in_open); push_input; index  $\leftarrow$  in_open; eof_seen[index]  $\leftarrow$  false;
  grp_stack[index]  $\leftarrow$  cur_boundary; if_stack[index]  $\leftarrow$  cond_ptr; line_stack[index]  $\leftarrow$  line; start  $\leftarrow$  first;
  state  $\leftarrow$  mid_line; name  $\leftarrow$  0; { terminal_input is now true }
  end;
```

351. Conversely, the variables must be downdated when such a level of input is finished:

```
procedure end_file_reading;
  begin first  $\leftarrow$  start; line  $\leftarrow$  line_stack[index];
  if (name = 18)  $\vee$  (name = 19) then pseudo_close
  else if name > 17 then a_close(cur_file); { forget it }
  pop_input; decr(in_open);
  end;
```

352. In order to keep the stack from overflowing during a long sequence of inserted ‘\show’ commands, the following routine removes completed error-inserted lines from memory.

```
procedure clear_for_error_prompt;
  begin while (state  $\neq$  token_list)  $\wedge$  terminal_input  $\wedge$  (input_ptr > 0)  $\wedge$  (loc > limit) do end_file_reading;
  print_ln; clear_terminal;
  end;
```

353. To get TeX's whole input mechanism going, we perform the following actions.

(Initialize the input routines 353) \equiv

```
begin input_ptr  $\leftarrow$  0; max_in_stack  $\leftarrow$  0; in_open  $\leftarrow$  0; open_parens  $\leftarrow$  0; max_buf_stack  $\leftarrow$  0;
grp_stack[0]  $\leftarrow$  0; if_stack[0]  $\leftarrow$  null; param_ptr  $\leftarrow$  0; max_param_stack  $\leftarrow$  0; first  $\leftarrow$  buf_size;
repeat buffer[first]  $\leftarrow$  0; decr(first);
until first = 0;
scanner_status  $\leftarrow$  normal; warning_index  $\leftarrow$  null; first  $\leftarrow$  1; state  $\leftarrow$  new_line; start  $\leftarrow$  1; index  $\leftarrow$  0;
line  $\leftarrow$  0; name  $\leftarrow$  0; force_eof  $\leftarrow$  false; align_state  $\leftarrow$  1000000;
if  $\neg$ init_terminal then goto final_end;
limit  $\leftarrow$  last; first  $\leftarrow$  last + 1; { init_terminal has set loc and last }
end
```

This code is used in section 1515.

354. Getting the next token. The heart of \TeX 's input mechanism is the *get_next* procedure, which we shall develop in the next few sections of the program. Perhaps we shouldn't actually call it the "heart," however, because it really acts as \TeX 's eyes and mouth, reading the source files and gobbling them up. And it also helps \TeX to regurgitate stored token lists that are to be processed again.

The main duty of *get_next* is to input one token and to set *cur_cmd* and *cur_chr* to that token's command code and modifier. Furthermore, if the input token is a control sequence, the *eqtb* location of that control sequence is stored in *cur_cs*; otherwise *cur_cs* is set to zero.

Underlying this simple description is a certain amount of complexity because of all the cases that need to be handled. However, the inner loop of *get_next* is reasonably short and fast.

When *get_next* is asked to get the next token of a `\read` line, it sets *cur_cmd* = *cur_chr* = *cur_cs* = 0 in the case that no more tokens appear on that line. (There might not be any tokens at all, if the *end_line_char* has *ignore* as its catcode.)

355. The value of *par_loc* is the *eqtb* address of '`\par`'. This quantity is needed because a blank line of input is supposed to be exactly equivalent to the appearance of `\par`; we must set *cur_cs* \leftarrow *par_loc* when detecting a blank line.

```
<Global variables 13> +=
par_loc: pointer; {location of '\par' in eqtb}
par_token: halfword; {token representing '\par'}
```

356. <Put each of \TeX 's primitives into the hash table 244> +=
primitive("par", *par_end*, 256); {cf. *scan_file_name*}
par_loc \leftarrow *cur_val*; *par_token* \leftarrow *cs_token_flag* + *par_loc*;

357. <Cases of *print_cmd_chr* for symbolic printing of primitives 245> +=
par_end: *print_esc*("par");

358. Before getting into *get_next*, let's consider the subroutine that is called when an '`\outer`' control sequence has been scanned or when the end of a file has been reached. These two cases are distinguished by *cur_cs*, which is zero at the end of a file.

```
procedure check_outer_validity;
var p: pointer; {points to inserted token list}
    q: pointer; {auxiliary pointer}
begin if scanner_status  $\neq$  normal then
  begin deletions_allowed  $\leftarrow$  false; <Back up an outer control sequence so that it can be reread 359>;
  if scanner_status > skipping then <Tell the user what has run away and try to recover 360>
  else begin print_err("Incomplete_"); print_cmd_chr(if_test, cur_if);
    print(";_all_text_was_ignored_after_line_"); print_int(skip_line);
    help3("A_forbidden_control_sequence_occurred_in_skipped_text.")
    ("This_kind_of_error_happens_when_you_say_\`if...\`_and_forget")
    ("the_matching_\`fi\`._I've_inserted_a_\`fi\`;_this_might_work.");
    if cur_cs  $\neq$  0 then cur_cs  $\leftarrow$  0
    else help_line[2]  $\leftarrow$  "The_file_ended_while_I_was_skipping_conditional_text.";
    cur_tok  $\leftarrow$  cs_token_flag + frozen_fi; ins_error;
    end;
  deletions_allowed  $\leftarrow$  true;
end;
end;
```

359. An outer control sequence that occurs in a `\read` will not be reread, since the error recovery for `\read` is not very powerful.

```

⟨Back up an outer control sequence so that it can be reread 359⟩ ≡
  if cur_cs ≠ 0 then
    begin if (state = token_list) ∨ (name < 1) ∨ (name > 17) then
      begin p ← get_avail; info(p) ← cs_token_flag + cur_cs; back_list(p);
        {prepare to read the control sequence again}
      end;
      cur_cmd ← spacer; cur_chr ← "␣"; {replace it by a space}
    end

```

This code is used in section 358.

```

360. ⟨Tell the user what has run away and try to recover 360⟩ ≡
  begin runaway; {print a definition, argument, or preamble}
  if cur_cs = 0 then print_err("File␣ended")
  else begin cur_cs ← 0; print_err("Forbidden␣control␣sequence␣found");
    end;
  print("␣while␣scanning␣"); ⟨Print either ‘definition’ or ‘use’ or ‘preamble’ or ‘text’, and insert
    tokens that should lead to recovery 361⟩;
  print("␣of␣"); sprint_cs(warning_index);
  help4("I␣suspect␣you␣have␣forgotten␣a␣`´,␣causing␣me")
  ("to␣read␣past␣where␣you␣wanted␣me␣to␣stop.")
  ("I´ll␣try␣to␣recover;␣but␣if␣the␣error␣is␣serious,")
  ("you´d␣better␣type␣`E´␣or␣`X´␣now␣and␣fix␣your␣file.");
  error;
  end

```

This code is used in section 358.

361. The recovery procedure can’t be fully understood without knowing more about the TeX routines that should be aborted, but we can sketch the ideas here: For a runaway definition or a runaway balanced text we will insert a right brace; for a runaway preamble, we will insert a special `\cr` token and a right brace; and for a runaway argument, we will set *long_state* to *outer_call* and insert `\par`.

```

⟨Print either ‘definition’ or ‘use’ or ‘preamble’ or ‘text’, and insert tokens that should lead to
  recovery 361⟩ ≡
  p ← get_avail;
  case scanner_status of
    defining: begin print("definition"); info(p) ← right_brace_token + "␣";
      end;
    matching: begin print("use"); info(p) ← par_token; long_state ← outer_call;
      end;
    aligning: begin print("preamble"); info(p) ← right_brace_token + "␣"; q ← p; p ← get_avail;
      link(p) ← q; info(p) ← cs_token_flag + frozen_cr; align_state ← −1000000;
      end;
    absorbing: begin print("text"); info(p) ← right_brace_token + "␣";
      end;
  end; {there are no other cases}
  ins_list(p)

```

This code is used in section 360.

362. We need to mention a procedure here that may be called by *get_next*.
procedure *firm_up_the_line*; *forward*;

363. Now we're ready to take the plunge into *get_next* itself. Parts of this routine are executed more often than any other instructions of TeX.

```

define switch = 25 { a label in get_next }
define start_cs = 26 { another }

procedure get_next; { sets cur_cmd, cur_chr, cur_cs to next token }
  label restart, { go here to get the next input token }
    switch, { go here to eat the next character from a file }
    reswitch, { go here to digest it again }
    start_cs, { go here to start looking for a control sequence }
    found, { go here when a control sequence has been found }
    exit; { go here when the next input token has been got }
  var k: 0 .. buf_size; { an index into buffer }
    t: halfword; { a token }
    cat: 0 .. max_char_code; { cat_code(cur_chr), usually }
    c, cc: ASCII_code; { constituents of a possible expanded code }
    d: 2 .. 3; { number of excess characters in an expanded code }
  begin restart: cur_cs ← 0;
  if state ≠ token_list then ⟨Input from external file, goto restart if no input found 365⟩
  else ⟨Input from token list, goto restart if end of list or if a parameter needs to be expanded 379⟩;
  ⟨If an alignment entry has just ended, take appropriate action 364⟩;
exit: end;

```

364. An alignment entry ends when a tab or \cr occurs, provided that the current level of braces is the same as the level that was present at the beginning of that alignment entry; i.e., provided that *align_state* has returned to the value it had after the ⟨*u_j*⟩ template for that entry.

⟨If an alignment entry has just ended, take appropriate action 364⟩ ≡

```

if cur_cmd ≤ car_ret then
  if cur_cmd ≥ tab_mark then
    if align_state = 0 then ⟨Insert the ⟨vj⟩ template and goto restart 963⟩

```

This code is used in section 363.

365. ⟨Input from external file, **goto** *restart* if no input found 365⟩ ≡

```

begin switch: if loc ≤ limit then { current line not yet finished }
  begin cur_chr ← buffer[loc]; incr(loc);
  reswitch: cur_cmd ← cat_code(cur_chr); ⟨Change state if necessary, and goto switch if the current
    character should be ignored, or goto reswitch if the current character changes to another 366⟩;
  end
else begin state ← new_line;
  ⟨Move to next line of file, or goto restart if there is no next line, or return if a \read line has
    finished 382⟩;
  check_interrupt; goto switch;
end;
end

```

This code is used in section 363.

366. The following 48-way switch accomplishes the scanning quickly, assuming that a decent Pascal compiler has translated the code. Note that the numeric values for *mid_line*, *skip_blanks*, and *new_line* are spaced apart from each other by *max_char_code* + 1, so we can add a character's command code to the state to get a single number that characterizes both.

```
define any_state_plus(#)  $\equiv$  mid_line + #, skip_blanks + #, new_line + #
< Change state if necessary, and goto switch if the current character should be ignored, or goto reswitch if
  the current character changes to another 366 >  $\equiv$ 
case state + cur_cmd of
  < Cases where character is ignored 367 >: goto switch;
  any_state_plus(escape): < Scan a control sequence and set state  $\leftarrow$  skip_blanks or mid_line 376 >;
  any_state_plus(active_char): < Process an active-character control sequence and set state  $\leftarrow$  mid_line 375 >;
  any_state_plus(sup_mark): < If this sup_mark starts an expanded character like ^^A or ^^df, then goto
    reswitch, otherwise set state  $\leftarrow$  mid_line 374 >;
  any_state_plus(invalid_char): < Decry the invalid character and goto restart 368 >;
  < Handle situations involving spaces, braces, changes of state 369 >
othercases do_nothing
endcases
```

This code is used in section 365.

367. < Cases where character is ignored 367 > \equiv
any_state_plus(ignore), *skip_blanks* + *spacer*, *new_line* + *spacer*

This code is used in section 366.

368. We go to *restart* instead of to *switch*, because *state* might equal *token_list* after the error has been dealt with (cf. *clear_for_error_prompt*).

```
< Decry the invalid character and goto restart 368 >  $\equiv$ 
begin print_err("Text_line_contains_an_invalid_character");
help2("A_funny_symbol_that_I_can't_read_has_just_been_input.");
("Continue,_and_I'll_forget_that_it_ever_happened.");
deletions_allowed  $\leftarrow$  false; error; deletions_allowed  $\leftarrow$  true; goto restart;
end
```

This code is used in section 366.

369. **define** *add_delims_to*(#) \equiv # + *math_shift*, # + *tab_mark*, # + *mac_param*, # + *sub_mark*, # + *letter*,
 # + *other_char*

```
< Handle situations involving spaces, braces, changes of state 369 >  $\equiv$ 
mid_line + spacer: < Enter skip_blanks state, emit a space 371 >;
mid_line + car_ret: < Finish line, emit a space 370 >;
skip_blanks + car_ret, any_state_plus(comment): < Finish line, goto switch 372 >;
new_line + car_ret: < Finish line, emit a \par 373 >;
mid_line + left_brace: incr(align_state);
skip_blanks + left_brace, new_line + left_brace: begin state  $\leftarrow$  mid_line; incr(align_state);
end;
mid_line + right_brace: decr(align_state);
skip_blanks + right_brace, new_line + right_brace: begin state  $\leftarrow$  mid_line; decr(align_state);
end;
add_delims_to(skip_blanks), add_delims_to(new_line): state  $\leftarrow$  mid_line;
```

This code is used in section 366.

370. When a character of type *spacer* gets through, its character code is changed to `"␣" = '40`. This means that the ASCII codes for tab and space, and for the space inserted at the end of a line, will be treated alike when macro parameters are being matched. We do this since such characters are indistinguishable on most computer terminal displays.

⟨Finish line, emit a space 370⟩ ≡

```
begin loc ← limit + 1; cur_cmd ← spacer; cur_chr ← "␣";  
end
```

This code is used in section 369.

371. The following code is performed only when *cur_cmd* = *spacer*.

⟨Enter *skip_blanks* state, emit a space 371⟩ ≡

```
begin state ← skip_blanks; cur_chr ← "␣";  
end
```

This code is used in section 369.

372. ⟨Finish line, **goto** *switch* 372⟩ ≡

```
begin loc ← limit + 1; goto switch;  
end
```

This code is used in section 369.

373. ⟨Finish line, emit a `\par` 373⟩ ≡

```
begin loc ← limit + 1; cur_cs ← par_loc; cur_cmd ← eq_type(cur_cs); cur_chr ← equiv(cur_cs);  
if cur_cmd ≥ outer_call then check_outer_validity;  
end
```

This code is used in section 369.

374. Notice that a code like `^^8` becomes `x` if not followed by a hex digit.

```
define is_hex(#) ≡ (((# ≥ "0") ∧ (# ≤ "9")) ∨ ((# ≥ "a") ∧ (# ≤ "f")))  
define hex_to_cur_chr ≡  
    if c ≤ "9" then cur_chr ← c - "0" else cur_chr ← c - "a" + 10;  
    if cc ≤ "9" then cur_chr ← 16 * cur_chr + cc - "0"  
    else cur_chr ← 16 * cur_chr + cc - "a" + 10
```

⟨If this *sup_mark* starts an expanded character like `^^A` or `^^df`, then **goto** *reswitch*, otherwise set *state* ← *mid_line* 374⟩ ≡

```
begin if cur_chr = buffer[loc] then  
    if loc < limit then  
        begin c ← buffer[loc + 1]; if c < '200 then { yes we have an expanded char }  
        begin loc ← loc + 2;  
        if is_hex(c) then  
            if loc ≤ limit then  
                begin cc ← buffer[loc]; if is_hex(cc) then  
                    begin incr(loc); hex_to_cur_chr; goto reswitch;  
                    end;  
                end;  
            if c < '100 then cur_chr ← c + '100 else cur_chr ← c - '100;  
            goto reswitch;  
        end;  
    end;  
    state ← mid_line;  
end
```

This code is used in section 366.

375. \langle Process an active-character control sequence and set $state \leftarrow mid_line$ 375 $\rangle \equiv$
begin $cur_cs \leftarrow cur_chr + active_base$; $cur_cmd \leftarrow eq_type(cur_cs)$; $cur_chr \leftarrow equiv(cur_cs)$;
 $state \leftarrow mid_line$;
if $cur_cmd \geq outer_call$ **then** $check_outer_validity$;
end

This code is used in section 366.

376. Control sequence names are scanned only when they appear in some line of a file; once they have been scanned the first time, their *eqtb* location serves as a unique identification, so TEX doesn't need to refer to the original name any more except when it prints the equivalent in symbolic form.

The program that scans a control sequence has been written carefully in order to avoid the blowups that might otherwise occur if a malicious user tried something like '\catcode`15=0'. The algorithm might look at $buffer[limit + 1]$, but it never looks at $buffer[limit + 2]$.

If expanded characters like '^A' or '^df' appear in or just following a control sequence name, they are converted to single characters in the buffer and the process is repeated, slowly but surely.

\langle Scan a control sequence and set $state \leftarrow skip_blanks$ or mid_line 376 $\rangle \equiv$
begin if $loc > limit$ **then** $cur_cs \leftarrow null_cs$ { $state$ is irrelevant in this case }
else begin $start_cs: k \leftarrow loc$; $cur_chr \leftarrow buffer[k]$; $cat \leftarrow cat_code(cur_chr)$; $incr(k)$;
if $cat = letter$ **then** $state \leftarrow skip_blanks$
else if $cat = spacer$ **then** $state \leftarrow skip_blanks$
else $state \leftarrow mid_line$;
if $(cat = letter) \wedge (k \leq limit)$ **then** \langle Scan ahead in the buffer until finding a nonletter; if an expanded code is encountered, reduce it and **goto** $start_cs$; otherwise if a multiletter control sequence is found, adjust cur_cs and loc , and **goto** $found$ 378 \rangle
else \langle If an expanded code is present, reduce it and **goto** $start_cs$ 377 \rangle ;
 $cur_cs \leftarrow single_base + buffer[loc]$; $incr(loc)$;
end;
 $found: cur_cmd \leftarrow eq_type(cur_cs)$; $cur_chr \leftarrow equiv(cur_cs)$;
if $cur_cmd \geq outer_call$ **then** $check_outer_validity$;
end

This code is used in section 366.

377. Whenever we reach the following piece of code, we will have $cur_chr = buffer[k-1]$ and $k \leq limit + 1$ and $cat = cat_code(cur_chr)$. If an expanded code like $\sim A$ or $\sim df$ appears in $buffer[(k-1) \dots (k+1)]$ or $buffer[(k-1) \dots (k+2)]$, we will store the corresponding code in $buffer[k-1]$ and shift the rest of the buffer left two or three places.

\langle If an expanded code is present, reduce it and **goto** *start_cs* 377 $\rangle \equiv$

```

begin if  $buffer[k] = cur\_chr$  then if  $cat = sup\_mark$  then if  $k < limit$  then
  begin  $c \leftarrow buffer[k+1]$ ; if  $c < '200$  then { yes, one is indeed present }
    begin  $d \leftarrow 2$ ;
    if  $is\_hex(c)$  then if  $k+2 \leq limit$  then
      begin  $cc \leftarrow buffer[k+2]$ ; if  $is\_hex(cc)$  then  $incr(d)$ ;
      end;
    if  $d > 2$  then
      begin  $hex\_to\_cur\_chr$ ;  $buffer[k-1] \leftarrow cur\_chr$ ;
      end
    else if  $c < '100$  then  $buffer[k-1] \leftarrow c + '100$ 
    else  $buffer[k-1] \leftarrow c - '100$ ;
     $limit \leftarrow limit - d$ ;  $first \leftarrow first - d$ ;
    while  $k \leq limit$  do
      begin  $buffer[k] \leftarrow buffer[k+d]$ ;  $incr(k)$ ;
      end;
    goto start_cs;
  end;
end;
end;

```

end

This code is used in sections 376 and 378.

378. \langle Scan ahead in the buffer until finding a nonletter; if an expanded code is encountered, reduce it and **goto** *start_cs*; otherwise if a multiletter control sequence is found, adjust *cur_cs* and *loc*, and **goto** *found* 378 $\rangle \equiv$

```

begin repeat  $cur\_chr \leftarrow buffer[k]$ ;  $cat \leftarrow cat\_code(cur\_chr)$ ;  $incr(k)$ ;
until  $(cat \neq letter) \vee (k > limit)$ ;
 $\langle$  If an expanded code is present, reduce it and goto start_cs 377  $\rangle$ ;
if  $cat \neq letter$  then  $decr(k)$ ; { now  $k$  points to first nonletter }
if  $k > loc + 1$  then { multiletter control sequence has been scanned }
  begin  $cur\_cs \leftarrow id\_lookup(loc, k - loc)$ ;  $loc \leftarrow k$ ; goto found;
  end;
end

```

end

This code is used in section 376.

379. Let's consider now what happens when *get_next* is looking at a token list.

```

⟨Input from token list, goto restart if end of list or if a parameter needs to be expanded 379⟩ ≡
  if loc ≠ null then { list not exhausted }
    begin t ← info(loc); loc ← link(loc); { move to next }
    if t ≥ cs_token_flag then { a control sequence token }
      begin cur_cs ← t − cs_token_flag; cur_cmd ← eq_type(cur_cs); cur_chr ← equiv(cur_cs);
      if cur_cmd ≥ outer_call then
        if cur_cmd = dont_expand then ⟨Get the next token, suppressing expansion 380⟩
        else check_outer_validity;
      end
    else begin cur_cmd ← t div '400; cur_chr ← t mod '400;
      case cur_cmd of
        left_brace: incr(align_state);
        right_brace: decr(align_state);
        out_param: ⟨Insert macro parameter and goto restart 381⟩;
        othercases do_nothing
      endcases;
    end;
  end
else begin { we are done with this token list }
  end_token_list; goto restart; { resume previous level }
end

```

This code is used in section 363.

380. The present point in the program is reached only when the *expand* routine has inserted a special marker into the input. In this special case, *info*(*loc*) is known to be a control sequence token, and *link*(*loc*) = *null*.

```

define no_expand_flag = 257 { this characterizes a special variant of relax }
⟨Get the next token, suppressing expansion 380⟩ ≡
  begin cur_cs ← info(loc) − cs_token_flag; loc ← null;
  cur_cmd ← eq_type(cur_cs); cur_chr ← equiv(cur_cs);
  if cur_cmd > max_command then
    begin cur_cmd ← relax; cur_chr ← no_expand_flag;
    end;
  end

```

This code is used in section 379.

```

381. ⟨Insert macro parameter and goto restart 381⟩ ≡
  begin begin_token_list(param_stack[param_start + cur_chr − 1], parameter); goto restart;
  end

```

This code is used in section 379.

382. All of the easy branches of *get_next* have now been taken care of. There is one more branch.

```

define end_line_char_inactive  $\equiv (end\_line\_char < 0) \vee (end\_line\_char > 255)$ 
⟨Move to next line of file, or goto restart if there is no next line, or return if a \read line has
finished 382⟩  $\equiv$ 
if name > 17 then ⟨Read next line of file into buffer, or goto restart if the file has ended 384⟩
else begin if  $\neg terminal\_input$  then { \read line has ended }
    begin cur_cmd  $\leftarrow$  0; cur_chr  $\leftarrow$  0; return;
end;
if input_ptr > 0 then { text was inserted during error recovery }
    begin end_file_reading; goto restart; { resume previous level }
end;
if selector < log_only then open_log_file;
if interaction > nonstop_mode then
    begin if end_line_char_inactive then incr(limit);
    if limit = start then { previous line was empty }
        print_nl("(Please_type_a_command_or_say_`end`");
    print_ln; first  $\leftarrow$  start; prompt_input("*"); { input on-line into buffer }
    limit  $\leftarrow$  last;
    if end_line_char_inactive then decr(limit)
    else buffer[limit]  $\leftarrow$  end_line_char;
    first  $\leftarrow$  limit + 1; loc  $\leftarrow$  start;
    end
else fatal_error("***_(job_aborted,_no_legal_end_found)");
    { nonstop mode, which is intended for overnight batch processing, never waits for on-line input }
end

```

This code is used in section 365.

383. The global variable *force_eof* is normally *false*; it is set *true* by an `\endinput` command.

⟨Global variables 13⟩ $+\equiv$

force_eof: *boolean*; { should the next `\input` be aborted early? }

```

384.  ⟨ Read next line of file into buffer, or goto restart if the file has ended 384 ⟩ ≡
begin incr(line); first ← start;
if ¬force_eof then
  if name ≤ 19 then
    begin if pseudo_input then { not end of file }
      firm_up_the_line { this sets limit }
    else if (every_eof ≠ null) ∧ ¬eof_seen[index] then
      begin limit ← first − 1; eof_seen[index] ← true; { fake one empty line }
      begin_token_list(every_eof, every_eof_text); goto restart;
      end
    else force_eof ← true;
  end
else begin if input_ln(cur_file, true) then { not end of file }
  firm_up_the_line { this sets limit }
  else if (every_eof ≠ null) ∧ ¬eof_seen[index] then
    begin limit ← first − 1; eof_seen[index] ← true; { fake one empty line }
    begin_token_list(every_eof, every_eof_text); goto restart;
    end
    else force_eof ← true;
  end;
if force_eof then
  begin if tracing_nesting > 0 then
    if (grp_stack[in_open] ≠ cur_boundary) ∨ (if_stack[in_open] ≠ cond_ptr) then file_warning;
    { give warning for some unfinished groups and/or conditionals }
  if name ≥ 19 then
    begin print_char(""); decr(open_parens); update_terminal; { show user that file has been read }
    end;
  force_eof ← false; end_file_reading; { resume previous level }
  check_outer_validity; goto restart;
end;
if end_line_char_inactive then decr(limit)
else buffer[limit] ← end_line_char;
first ← limit + 1; loc ← start; { ready to read }
end

```

This code is used in section 382.

385. If the user has set the *pausing* parameter to some positive value, and if nonstop mode has not been selected, each line of input is displayed on the terminal and the transcript file, followed by ‘=>’. T_EX waits for a response. If the response is simply *carriage-return*, the line is accepted as it stands, otherwise the line typed is used instead of the line in the file.

```
procedure firm_up_the_line;
  var k: 0 .. buf_size; { an index into buffer }
  begin limit  $\leftarrow$  last;
  if pausing > 0 then
    if interaction > nonstop_mode then
      begin wake_up_terminal; print_ln;
      if start < limit then
        for k  $\leftarrow$  start to limit - 1 do print(buffer[k]);
        first  $\leftarrow$  limit; prompt_input("=>"); { wait for user response }
        if last > first then
          begin for k  $\leftarrow$  first to last - 1 do { move line down in buffer }
            buffer[k + start - first]  $\leftarrow$  buffer[k];
          limit  $\leftarrow$  start + last - first;
          end;
        end;
      end;
    end;
```

386. Since *get_next* is used so frequently in T_EX, it is convenient to define three related procedures that do a little more:

get_token not only sets *cur_cmd* and *cur_chr*, it also sets *cur_tok*, a packed halfword version of the current token.

get_x_token, meaning “get an expanded token,” is like *get_token*, but if the current token turns out to be a user-defined control sequence (i.e., a macro call), or a conditional, or something like `\topmark` or `\expandafter` or `\csname`, it is eliminated from the input by beginning the expansion of the macro or the evaluation of the conditional.

x_token is like *get_x_token* except that it assumes that *get_next* has already been called.

In fact, these three procedures account for almost every use of *get_next*.

387. No new control sequences will be defined except during a call of *get_token*, or when `\csname` compresses a token list, because *no_new_control_sequence* is always *true* at other times.

```
procedure get_token; { sets cur_cmd, cur_chr, cur_tok }
  begin no_new_control_sequence  $\leftarrow$  false; get_next; no_new_control_sequence  $\leftarrow$  true;
  if cur_cs = 0 then cur_tok  $\leftarrow$  (cur_cmd * '400) + cur_chr
  else cur_tok  $\leftarrow$  cs_token_flag + cur_cs;
  end;
```

388. Expanding the next token. Only a dozen or so command codes $> \text{max_command}$ can possibly be returned by *get_next*; in increasing order, they are *undefined_cs*, *expand_after*, *no_expand*, *input*, *if_test*, *fi_or_else*, *cs_name*, *convert*, *the*, *top_bot_mark*, *call*, *long_call*, *outer_call*, *long_outer_call*, and *end_template*.

The *expand* subroutine is used when *cur_cmd* $> \text{max_command}$. It removes a “call” or a conditional or one of the other special operations just listed. It follows that *expand* might invoke itself recursively. In all cases, *expand* destroys the current token, but it sets things up so that the next *get_next* will deliver the appropriate next token. The value of *cur_tok* need not be known when *expand* is called.

Since several of the basic scanning routines communicate via global variables, their values are saved as local variables of *expand* so that recursive calls don’t invalidate them.

```

⟨Declare the procedure called macro_call 415⟩
⟨Declare the procedure called insert_relax 405⟩
⟨Declare  $\varepsilon$ -TeX procedures for expanding 1749⟩
procedure pass_text; forward;
procedure start_input; forward;
procedure conditional; forward;
procedure get_x_token; forward;
procedure conv_toks; forward;
procedure ins_the_toks; forward;
procedure expand;
  label reswitch;
  var t: halfword; { token that is being “expanded after” }
      b: boolean; { keep track of nested csnames }
      p, q, r: pointer; { for list manipulation }
      j: 0 .. buf_size; { index into buffer }
      cv_backup: integer; { to save the global quantity cur_val }
      cvl_backup, radix_backup, co_backup: small_number; { to save cur_val_level, etc. }
      backup_backup: pointer; { to save link(backup_head) }
      save_scanner_status: small_number; { temporary storage of scanner_status }
  begin cv_backup  $\leftarrow$  cur_val; cvl_backup  $\leftarrow$  cur_val_level; radix_backup  $\leftarrow$  radix; co_backup  $\leftarrow$  cur_order;
      backup_backup  $\leftarrow$  link(backup_head);
  reswitch: if cur_cmd  $<$  call then ⟨Expand a nonmacro 391⟩
      else if cur_cmd  $<$  end_template then macro_call
          else ⟨Insert a token containing frozen_endv 401⟩;
      cur_val  $\leftarrow$  cv_backup; cur_val_level  $\leftarrow$  cvl_backup; radix  $\leftarrow$  radix_backup; cur_order  $\leftarrow$  co_backup;
      link(backup_head)  $\leftarrow$  backup_backup;
  end;

```

389. ⟨Global variables 13⟩ \equiv

is_in_csname: *boolean*;

390. ⟨Set initial values of key variables 21⟩ \equiv

is_in_csname \leftarrow *false*;

391. $\langle \text{Expand a nonmacro 391} \rangle \equiv$

```

begin if tracing.commands > 1 then show_cur_cmd_chr;
case cur_cmd of
  top_bot_mark:  $\langle \text{Insert the appropriate mark text into the scanner 412} \rangle$ ;
  expand_after: if cur_chr = 0 then  $\langle \text{Expand the token after the next token 392} \rangle$ 
    else  $\langle \text{Negate a boolean conditional and goto reswitch 1762} \rangle$ ;
  no_expand: if cur_chr = 0 then  $\langle \text{Suppress expansion of the next token 393} \rangle$ 
    else  $\langle \text{Implement \pdfprimitive 394} \rangle$ ;
  cs_name:  $\langle \text{Manufacture a control sequence name 398} \rangle$ ;
  convert: conv_toks; { this procedure is discussed in Part 27 below }
  the: ins_the_toks; { this procedure is discussed in Part 27 below }
  if_test: conditional; { this procedure is discussed in Part 28 below }
  fi_or_else:  $\langle \text{Terminate the current conditional and skip to \fi 536} \rangle$ ;
  input:  $\langle \text{Initiate or terminate input from a file 404} \rangle$ ;
  othercases  $\langle \text{Complain about an undefined macro 396} \rangle$ 
endcases;
end

```

This code is used in section 388.

392. It takes only a little shuffling to do what T_EX calls `\expandafter`.

$\langle \text{Expand the token after the next token 392} \rangle \equiv$

```

begin get_token; t  $\leftarrow$  cur_tok; get_token;
if cur_cmd > max_command then expand else back_input;
cur_tok  $\leftarrow$  t; back_input;
end

```

This code is used in section 391.

393. The implementation of `\noexpand` is a bit trickier, because it is necessary to insert a special ‘*dont_expand*’ marker into T_EX’s reading mechanism. This special marker is processed by *get_next*, but it does not slow down the inner loop.

Since `\outer` macros might arise here, we must also clear the *scanner_status* temporarily.

$\langle \text{Suppress expansion of the next token 393} \rangle \equiv$

```

begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  normal; get_token;
scanner_status  $\leftarrow$  save_scanner_status; t  $\leftarrow$  cur_tok; back_input;
  { now start and loc point to the backed-up token t }
if t  $\geq$  cs_token_flag then
  begin p  $\leftarrow$  get_avail; info(p)  $\leftarrow$  cs_token_flag + frozen_dont_expand; link(p)  $\leftarrow$  loc; start  $\leftarrow$  p;
    loc  $\leftarrow$  p;
  end;
end

```

This code is used in section 391.

394. The `\pdfprimitive` handling. If the primitive meaning of the next token is an expandable command, it suffices to replace the current token with the primitive one and restart *expand*.

Otherwise, the token we just read has to be pushed back, as well as a token matching the internal form of `\pdfprimitive`, that is sneaked in as an alternate form of *ignore_spaces*.

Simply pushing back a token that matches the correct internal command does not work, because approach would not survive roundtripping to a temporary file.

`<Implement \pdfprimitive 394> ≡`

```

begin save_scanner_status ← scanner_status; scanner_status ← normal; get_token;
scanner_status ← save_scanner_status;
if cur_cs < hash_base then cur_cs ← prim_lookup(cur_cs - single_base)
else cur_cs ← prim_lookup(text(cur_cs));
if cur_cs ≠ undefined_primitive then
  begin t ← prim_eq_type(cur_cs);
  if t > max_command then
    begin cur_cmd ← t; cur_chr ← prim_equiv(cur_cs); cur_tok ← (cur_cmd * '400) + cur_chr;
    cur_cs ← 0; goto reswitch;
  end
else begin back_input; { now loc and start point to a one-item list }
  p ← get_avail; info(p) ← cs_token_flag + frozen_primitive; link(p) ← loc; loc ← p; start ← p;
end;
end;
end

```

This code is used in section 391.

395. This block deals with unexpandable `\primitive` appearing at a spot where an integer or an internal values should have been found. It fetches the next token then resets *cur_cmd*, *cur_cs*, and *cur_tok*, based on the primitive value of that token. No expansion takes place, because the next token may be all sorts of things. This could trigger further expansion creating new errors.

`<Reset cur_tok for unexpandable primitives, goto restart 395> ≡`

```

begin get_token;
if cur_cs < hash_base then cur_cs ← prim_lookup(cur_cs - single_base)
else cur_cs ← prim_lookup(text(cur_cs));
if cur_cs ≠ undefined_primitive then
  begin cur_cmd ← prim_eq_type(cur_cs); cur_chr ← prim_equiv(cur_cs);
  cur_cs ← prim_eqtb_base + cur_cs; cur_tok ← cs_token_flag + cur_cs;
end
else begin cur_cmd ← relax; cur_chr ← 0; cur_tok ← cs_token_flag + frozen_relax;
  cur_cs ← frozen_relax;
end;
goto restart;
end

```

This code is used in sections 439 and 466.

396. \langle Complain about an undefined macro [396](#) $\rangle \equiv$

```

begin print_err("Undefined control sequence");
help5("The control sequence at the end of the top line")
("of your error message was never defined. If you have")
("misspelled it (e.g., \hobx´), type I and the correct")
("spelling (e.g., I\hbox´). Otherwise just continue,")
("and I'll forget about whatever was undefined."); error;
end

```

This code is used in section [391](#).

397. The *expand* procedure and some other routines that construct token lists find it convenient to use the following macros, which are valid only if the variables *p* and *q* are reserved for token-list building.

```

define store_new_token(#)  $\equiv$ 
  begin  $q \leftarrow get\_avail$ ;  $link(p) \leftarrow q$ ;  $info(q) \leftarrow \#$ ;  $p \leftarrow q$ ; {  $link(p)$  is null }
  end
define fast_store_new_token(#)  $\equiv$ 
  begin  $fast\_get\_avail(q)$ ;  $link(p) \leftarrow q$ ;  $info(q) \leftarrow \#$ ;  $p \leftarrow q$ ; {  $link(p)$  is null }
  end

```

398. \langle Manufacture a control sequence name [398](#) $\rangle \equiv$

```

begin  $r \leftarrow get\_avail$ ;  $p \leftarrow r$ ; { head of the list of characters }
 $b \leftarrow is\_in\_csname$ ;  $is\_in\_csname \leftarrow true$ ;
repeat  $get\_x\_token$ ;
  if  $cur\_cs = 0$  then store_new_token( $cur\_tok$ );
until  $cur\_cs \neq 0$ ;
if  $cur\_cmd \neq end\_cs\_name$  then  $\langle$  Complain about missing \endcsname 399  $\rangle$ ;
 $is\_in\_csname \leftarrow b$ ;  $\langle$  Look up the characters of list r in the hash table, and set cur_cs 400  $\rangle$ ;
flush_list( $r$ );
if  $eq\_type(cur\_cs) = undefined\_cs$  then
  begin  $eq\_define(cur\_cs, relax, 256)$ ; { N.B.: The save_stack might change }
  end; { the control sequence will now match ‘\relax’ }
 $cur\_tok \leftarrow cur\_cs + cs\_token\_flag$ ; back_input;
end

```

This code is used in section [391](#).

399. \langle Complain about missing `\endcsname` [399](#) $\rangle \equiv$

```

begin print_err("Missing"); print_esc("endcsname"); print("_inserted");
help2("The control sequence marked <to be read again> should")
("not appear between \csname and \endcsname."); back_error;
end

```

This code is used in sections [398](#) and [1764](#).

400. \langle Look up the characters of list r in the hash table, and set cur_cs 400 $\rangle \equiv$

```

j ← first; p ← link(r);
while p ≠ null do
  begin if j ≥ max_buf_stack then
    begin max_buf_stack ← j + 1;
    if max_buf_stack = buf_size then overflow("buffer_size", buf_size);
    end;
  buffer[j] ← info(p) mod 400; incr(j); p ← link(p);
  end;
if j > first + 1 then
  begin no_new_control_sequence ← false; cur_cs ← id_lookup(first, j - first);
  no_new_control_sequence ← true;
  end
else if j = first then cur_cs ← null_cs { the list is empty }
  else cur_cs ← single_base + buffer[first] { the list has length one }

```

This code is used in section 398.

401. An *end_template* command is effectively changed to an *endv* command by the following code. (The reason for this is discussed below; the *frozen_end_template* at the end of the template has passed the *check_outer_validity* test, so its mission of error detection has been accomplished.)

\langle Insert a token containing *frozen_endv* 401 $\rangle \equiv$

```

begin cur_tok ← cs_token_flag + frozen_endv; back_input;
end

```

This code is used in section 388.

402. The processing of `\input` involves the *start_input* subroutine, which will be declared later; the processing of `\endinput` is trivial.

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```

primitive("input", input, 0);
primitive("endinput", input, 1);

```

403. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```

input: if chr_code = 0 then print_esc("input")
   $\langle$  Cases of input for print_cmd_chr 1745  $\rangle$ 
else print_esc("endinput");

```

404. \langle Initiate or terminate input from a file 404 $\rangle \equiv$

```

if cur_chr = 1 then force_eof ← true
   $\langle$  Cases for input 1746  $\rangle$ 
else if name_in_progress then insert_relax
  else start_input

```

This code is used in section 391.

405. Sometimes the expansion looks too far ahead, so we want to insert a harmless `\relax` into the user's input.

\langle Declare the procedure called *insert_relax* 405 $\rangle \equiv$

```

procedure insert_relax;
  begin cur_tok ← cs_token_flag + cur_cs; back_input; cur_tok ← cs_token_flag + frozen_relax; back_input;
  token_type ← inserted;
  end;

```

This code is used in section 388.

406. Here is a recursive procedure that is T_EX's usual way to get the next token of input. It has been slightly optimized to take account of common cases.

```

procedure get_x_token; { sets cur_cmd, cur_chr, cur_tok, and expands macros }
  label restart, done;
  begin restart: get_next;
  if cur_cmd ≤ max_command then goto done;
  if cur_cmd ≥ call then
    if cur_cmd < end_template then macro_call
    else begin cur_cs ← frozen_endv; cur_cmd ← endv; goto done; { cur_chr = null_list }
    end
  else expand;
  goto restart;
done: if cur_cs = 0 then cur_tok ← (cur_cmd * '400) + cur_chr
  else cur_tok ← cs_token_flag + cur_cs;
  end;

```

407. The *get_x_token* procedure is essentially equivalent to two consecutive procedure calls: *get_next*; *x_token*.

```

procedure x_token; { get_x_token without the initial get_next }
  begin while cur_cmd > max_command do
    begin expand; get_next;
    end;
  if cur_cs = 0 then cur_tok ← (cur_cmd * '400) + cur_chr
  else cur_tok ← cs_token_flag + cur_cs;
  end;

```

408. A control sequence that has been \def'ed by the user is expanded by T_EX's *macro_call* procedure.

Before we get into the details of *macro_call*, however, let's consider the treatment of primitives like \topmark, since they are essentially macros without parameters. The token lists for such marks are kept in a global array of five pointers; we refer to the individual entries of this array by symbolic names *top_mark*, etc. The value of *top_mark* is either *null* or a pointer to the reference count of a token list.

```

define marks_code ≡ 5 { add this for \topmarks etc. }
define top_mark_code = 0 { the mark in effect at the previous page break }
define first_mark_code = 1 { the first mark between top_mark and bot_mark }
define bot_mark_code = 2 { the mark in effect at the current page break }
define split_first_mark_code = 3 { the first mark found by \vsplit }
define split_bot_mark_code = 4 { the last mark found by \vsplit }
define top_mark ≡ cur_mark[top_mark_code]
define first_mark ≡ cur_mark[first_mark_code]
define bot_mark ≡ cur_mark[bot_mark_code]
define split_first_mark ≡ cur_mark[split_first_mark_code]
define split_bot_mark ≡ cur_mark[split_bot_mark_code]
<Global variables 13> +=
cur_mark: array [top_mark_code .. split_bot_mark_code] of pointer; { token lists for marks }

```

409. <Set initial values of key variables 21> +=

```

top_mark ← null; first_mark ← null; bot_mark ← null; split_first_mark ← null; split_bot_mark ← null;

```

410. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```
primitive("topmark", top_bot_mark, top_mark_code);
primitive("firstmark", top_bot_mark, first_mark_code);
primitive("botmark", top_bot_mark, bot_mark_code);
primitive("splitfirstmark", top_bot_mark, split_first_mark_code);
primitive("splitbotmark", top_bot_mark, split_bot_mark_code);
```

411. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
top_bot_mark: begin case (chr_code mod marks_code) of
  first_mark_code: print_esc("firstmark");
  bot_mark_code: print_esc("botmark");
  split_first_mark_code: print_esc("splitfirstmark");
  split_bot_mark_code: print_esc("splitbotmark");
othercases print_esc("topmark")
endcases;
if chr_code  $\geq$  marks_code then print_char("s");
end;
```

412. The following code is activated when *cur_cmd* = *top_bot_mark* and when *cur_chr* is a code like *top_mark_code*.

\langle Insert the appropriate mark text into the scanner 412 $\rangle \equiv$

```
begin t  $\leftarrow$  cur_chr mod marks_code;
if cur_chr  $\geq$  marks_code then scan_register_num else cur_val  $\leftarrow$  0;
if cur_val = 0 then cur_ptr  $\leftarrow$  cur_mark[t]
else  $\langle$  Compute the mark pointer for mark type t and class cur_val 1821  $\rangle$ ;
if cur_ptr  $\neq$  null then begin_token_list(cur_ptr, mark_text);
end
```

This code is used in section 391.

413. Now let's consider *macro_call* itself, which is invoked when TeX is scanning a control sequence whose *cur_cmd* is either *call*, *long_call*, *outer_call*, or *long_outer_call*. The control sequence definition appears in the token list whose reference count is in location *cur_chr* of *mem*.

The global variable *long_state* will be set to *call* or to *long_call*, depending on whether or not the control sequence disallows \backslash par in its parameters. The *get_next* routine will set *long_state* to *outer_call* and emit \backslash par, if a file ends or if an \backslash outer control sequence occurs in the midst of an argument.

\langle Global variables 13 $\rangle + \equiv$

```
long_state: call .. long_outer_call; { governs the acceptance of  $\backslash$ par }
```

414. The parameters, if any, must be scanned before the macro is expanded. Parameters are token lists without reference counts. They are placed on an auxiliary stack called *pstack* while they are being scanned, since the *param_stack* may be losing entries during the matching process. (Note that *param_stack* can't be gaining entries, since *macro_call* is the only routine that puts anything onto *param_stack*, and it is not recursive.)

\langle Global variables 13 $\rangle + \equiv$

```
pstack: array [0 .. 8] of pointer; { arguments supplied to a macro }
```

415. After parameter scanning is complete, the parameters are moved to the *param_stack*. Then the macro body is fed to the scanner; in other words, *macro_call* places the defined text of the control sequence at the top of TeX's input stack, so that *get_next* will proceed to read it next.

The global variable *cur_cs* contains the *eqtb* address of the control sequence being expanded, when *macro_call* begins. If this control sequence has not been declared `\long`, i.e., if its command code in the *eq_type* field is not *long_call* or *long_outer_call*, its parameters are not allowed to contain the control sequence `\par`. If an illegal `\par` appears, the macro call is aborted, and the `\par` will be rescanned.

⟨Declare the procedure called *macro_call* 415⟩ ≡

```
procedure macro_call; { invokes a user-defined control sequence }
  label exit, continue, done, done1, found;
  var r: pointer; { current node in the macro's token list }
    p: pointer; { current node in parameter token list being built }
    q: pointer; { new node being put into the token list }
    s: pointer; { backup pointer for parameter matching }
    t: pointer; { cycle pointer for backup recovery }
    u, v: pointer; { auxiliary pointers for backup recovery }
    rbrace_ptr: pointer; { one step before the last right_brace token }
    n: small_number; { the number of parameters scanned }
    unbalance: halfword; { unmatched left braces in current parameter }
    m: halfword; { the number of tokens or groups (usually) }
    ref_count: pointer; { start of the token list }
    save_scanner_status: small_number; { scanner_status upon entry }
    save_warning_index: pointer; { warning_index upon entry }
    match_chr: ASCII_code; { character used in parameter }
  begin save_scanner_status ← scanner_status; save_warning_index ← warning_index;
  warning_index ← cur_cs; ref_count ← cur_chr; r ← link(ref_count); n ← 0;
  if tracing_macros > 0 then ⟨Show the text of the macro being expanded 427⟩;
  if info(r) = protected_token then r ← link(r);
  if info(r) ≠ end_match_token then ⟨Scan the parameters and make link(r) point to the macro body;
    but return if an illegal \par is detected 417⟩;
  ⟨Feed the macro body and its parameters to the scanner 416⟩;
exit: scanner_status ← save_scanner_status; warning_index ← save_warning_index;
  end;
```

This code is used in section 388.

416. Before we put a new token list on the input stack, it is wise to clean off all token lists that have recently been depleted. Then a user macro that ends with a call to itself will not require unbounded stack space.

⟨Feed the macro body and its parameters to the scanner 416⟩ ≡

```
while (state = token_list) ∧ (loc = null) ∧ (token_type ≠ v_template) do end_token_list;
  { conserve stack space }
begin_token_list(ref_count, macro); name ← warning_index; loc ← link(r);
if n > 0 then
  begin if param_ptr + n > max_param_stack then
    begin max_param_stack ← param_ptr + n;
    if max_param_stack > param_size then overflow("parameter_stack_size", param_size);
    end;
  for m ← 0 to n − 1 do param_stack[param_ptr + m] ← pstack[m];
  param_ptr ← param_ptr + n;
  end
```

This code is used in section 415.

417. At this point, the reader will find it advisable to review the explanation of token list format that was presented earlier, since many aspects of that format are of importance chiefly in the *macro_call* routine.

The token list might begin with a string of compulsory tokens before the first *match* or *end_match*. In that case the macro name is supposed to be followed by those tokens; the following program will set $s = \text{null}$ to represent this restriction. Otherwise s will be set to the first token of a string that will delimit the next parameter.

```

⟨Scan the parameters and make link(r) point to the macro body; but return if an illegal  $\backslash\text{par}$  is
  detected 417⟩ ≡
begin scanner_status  $\leftarrow$  matching; unbalance  $\leftarrow$  0; long_state  $\leftarrow$  eq_type(cur_cs);
if long_state  $\geq$  outer_call then long_state  $\leftarrow$  long_state - 2;
repeat link(temp_head)  $\leftarrow$  null;
  if (info( $r$ ) > match_token + 255)  $\vee$  (info( $r$ ) < match_token) then  $s \leftarrow \text{null}$ 
  else begin match_chr  $\leftarrow$  info( $r$ ) - match_token;  $s \leftarrow \text{link}(r)$ ;  $r \leftarrow s$ ;  $p \leftarrow \text{temp\_head}$ ;  $m \leftarrow 0$ ;
  end;
  ⟨Scan a parameter until its delimiter string has been found; or, if  $s = \text{null}$ , simply scan the delimiter
    string 418⟩;
  { now info( $r$ ) is a token whose command code is either match or end_match }
until info( $r$ ) = end_match_token;
end

```

This code is used in section 415.

418. If *info*(r) is a *match* or *end_match* command, it cannot be equal to any token found by *get_token*. Therefore an undelimited parameter—i.e., a *match* that is immediately followed by *match* or *end_match*—will always fail the test '*cur_tok* = *info*(r)' in the following algorithm.

```

⟨Scan a parameter until its delimiter string has been found; or, if  $s = \text{null}$ , simply scan the delimiter
  string 418⟩ ≡
continue: get_token; { set cur_tok to the next token of input }
if cur_tok = info( $r$ ) then ⟨Advance  $r$ ; goto found if the parameter delimiter has been fully matched,
  otherwise goto continue 420⟩;
⟨Contribute the recently matched tokens to the current parameter, and goto continue if a partial match
  is still in effect; but abort if  $s = \text{null}$  423⟩;
if cur_tok = par_token then
  if long_state  $\neq$  long_call then ⟨Report a runaway argument and abort 422⟩;
if cur_tok < right_brace_limit then
  if cur_tok < left_brace_limit then ⟨Contribute an entire group to the current parameter 425⟩
  else ⟨Report an extra right brace and goto continue 421⟩
else ⟨Store the current token, but goto continue if it is a blank space that would become an undelimited
  parameter 419⟩;
incr( $m$ );
if info( $r$ ) > end_match_token then goto continue;
if info( $r$ ) < match_token then goto continue;
found: if  $s \neq \text{null}$  then ⟨Tidy up the parameter just scanned, and tuck it away 426⟩

```

This code is used in section 417.

419. \langle Store the current token, but **goto** *continue* if it is a blank space that would become an undelimited parameter 419 $\rangle \equiv$

```

begin if cur_tok = space_token then
  if info(r)  $\leq$  end_match_token then
    if info(r)  $\geq$  match_token then goto continue;
  store_new_token(cur_tok);
end

```

This code is used in section 418.

420. A slightly subtle point arises here: When the parameter delimiter ends with ‘#{’, the token list will have a left brace both before and after the *end_match*. Only one of these should affect the *align_state*, but both will be scanned, so we must make a correction.

\langle Advance *r*; **goto** *found* if the parameter delimiter has been fully matched, otherwise **goto** *continue* 420 $\rangle \equiv$

```

begin r  $\leftarrow$  link(r);
if (info(r)  $\geq$  match_token)  $\wedge$  (info(r)  $\leq$  end_match_token) then
  begin if cur_tok < left_brace_limit then decr(align_state);
  goto found;
  end
else goto continue;
end

```

This code is used in section 418.

421. \langle Report an extra right brace and **goto** *continue* 421 $\rangle \equiv$

```

begin back_input; print_err("Argument_of_"); sprint_cs(warning_index); print("_has_an_extra_");
help6("I've_run_across_a_`_`_that_doesn't_seem_to_match_anything.")
("For_example,_`def#a#1{...}`_and_`a`_would_produce")
("this_error._If_you_simply_proceed_now,_the_`par`_that")
("I've_just_inserted_will_cause_me_to_report_a_runaway")
("argument_that_might_be_the_root_of_the_problem._But_if")
("your_`_`_was_spurious,_just_type_`2`_and_it_will_go_away."); incr(align_state);
long_state  $\leftarrow$  call; cur_tok  $\leftarrow$  par_token; ins_error; goto continue;
end { a white lie; the \par won't always trigger a runaway }

```

This code is used in section 418.

422. If *long_state* = *outer_call*, a runaway argument has already been reported.

\langle Report a runaway argument and abort 422 $\rangle \equiv$

```

begin if long_state = call then
  begin runaway; print_err("Paragraph_ended_before_"); sprint_cs(warning_index);
  print("_was_complete");
  help3("I_suspect_you've_forgotten_a_`_`_,_causing_me_to_apply_this")
  ("control_sequence_too_much_text._How_can_we_recover?")
  ("My_plan_is_to_forget_the_whole_thing_and_hope_for_the_best."); back_error;
  end;
pstack[n]  $\leftarrow$  link(temp_head); align_state  $\leftarrow$  align_state - unbalance;
for m  $\leftarrow$  0 to n do flush_list(pstack[m]);
return;
end

```

This code is used in sections 418 and 425.

423. When the following code becomes active, we have matched tokens from s to the predecessor of r , and we have found that $cur_tok \neq info(r)$. An interesting situation now presents itself: If the parameter is to be delimited by a string such as ‘ab’, and if we have scanned ‘aa’, we want to contribute one ‘a’ to the current parameter and resume looking for a ‘b’. The program must account for such partial matches and for others that can be quite complex. But most of the time we have $s = r$ and nothing needs to be done.

Incidentally, it is possible for `\par` tokens to sneak in to certain parameters of non-`\long` macros. For example, consider a case like ‘`\def\aa#1\par!{...}`’ where the first `\par` is not followed by an exclamation point. In such situations it does not seem appropriate to prohibit the `\par`, so TeX keeps quiet about this bending of the rules.

⟨Contribute the recently matched tokens to the current parameter, and **goto** *continue* if a partial match is still in effect; but abort if $s = null$ 423⟩ \equiv

```

if  $s \neq r$  then
  if  $s = null$  then ⟨Report an improper use of the macro and abort 424⟩
  else begin  $t \leftarrow s$ ;
    repeat  $store\_new\_token(info(t)); incr(m); u \leftarrow link(t); v \leftarrow s$ ;
      loop begin if  $u = r$  then
        if  $cur\_tok \neq info(v)$  then goto done
        else begin  $r \leftarrow link(v)$ ; goto continue;
          end;
        if  $info(u) \neq info(v)$  then goto done;
         $u \leftarrow link(u); v \leftarrow link(v)$ ;
      end;
    done:  $t \leftarrow link(t)$ ;
  until  $t = r$ ;
   $r \leftarrow s$ ; { at this point, no tokens are recently matched }
end

```

This code is used in section 418.

424. ⟨Report an improper use of the macro and abort 424⟩ \equiv

```

begin  $print\_err("Use\_of\_")$ ;  $sprint\_cs(warning\_index)$ ;  $print("_doesn't\_match\_its\_definition")$ ;
 $help4("If\_you\_say,\_e.g.,\_`\def\aa1{...}`,\_then\_you\_must\_always")$ 
 $("put\_1'\_after\_`a',\_since\_control\_sequence\_names\_are")$ 
 $("made\_up\_of\_letters\_only.\_The\_macro\_here\_has\_not\_been")$ 
 $("followed\_by\_the\_required\_stuff,\_so\_I'm\_ignoring\_it.")$ ; error; return;
end

```

This code is used in section 423.

425. ⟨Contribute an entire group to the current parameter 425⟩ \equiv

```

begin  $unbalance \leftarrow 1$ ;
loop begin  $fast\_store\_new\_token(cur\_tok)$ ;  $get\_token$ ;
  if  $cur\_tok = par\_token$  then
    if  $long\_state \neq long\_call$  then ⟨Report a runaway argument and abort 422⟩;
  if  $cur\_tok < right\_brace\_limit$  then
    if  $cur\_tok < left\_brace\_limit$  then  $incr(unbalance)$ 
    else begin  $decr(unbalance)$ ;
      if  $unbalance = 0$  then goto done1;
    end;
  end;
done1:  $rbrace\_ptr \leftarrow p$ ;  $store\_new\_token(cur\_tok)$ ;
end

```

This code is used in section 418.

426. If the parameter consists of a single group enclosed in braces, we must strip off the enclosing braces. That's why *rbrace_ptr* was introduced.

⟨Tidy up the parameter just scanned, and tuck it away [426](#)⟩ ≡

```
begin if (m = 1) ∧ (info(p) < right_brace_limit) then
  begin link(rbrace_ptr) ← null; free_avail(p); p ← link(temp_head); pstack[n] ← link(p); free_avail(p);
  end
else pstack[n] ← link(temp_head);
incr(n);
if tracing_macros > 0 then
  begin begin_diagnostic; print_nl(match_chr); print_int(n); print("<-");
  show_token_list(pstack[n − 1], null, 1000); end_diagnostic(false);
  end;
end
```

This code is used in section [418](#).

427. ⟨Show the text of the macro being expanded [427](#)⟩ ≡

```
begin begin_diagnostic; print_ln; print_cs(warning_index); token_show(ref_count);
end_diagnostic(false);
end
```

This code is used in section [415](#).

428. Basic scanning subroutines. Let's turn now to some procedures that TeX calls upon frequently to digest certain kinds of patterns in the input. Most of these are quite simple; some are quite elaborate. Almost all of the routines call *get_x_token*, which can cause them to be invoked recursively.

429. The *scan_left_brace* routine is called when a left brace is supposed to be the next non-blank token. (The term “left brace” means, more precisely, a character whose catcode is *left_brace*.) TeX allows *\relax* to appear before the *left_brace*.

```

procedure scan_left_brace; { reads a mandatory left_brace }
  begin ⟨ Get the next non-blank non-relax non-call token 430 ⟩;
  if cur_cmd ≠ left_brace then
    begin print_err("Missing_{_inserted}");
    help4("A_left_brace_was_mandatory_here,_so_I've_put_one_in.")
    ("You_might_want_to_delete_and/or_insert_some_corrections")
    ("so_that_I_will_find_a_matching_right_brace_soon.")
    ("(If_you're_confused_by_all_this,_try_typing_`I`_now.)"); back_error;
    cur_tok ← left_brace_token + "{"; cur_cmd ← left_brace; cur_chr ← "{"; incr(align_state);
    end;
  end;

```

430. ⟨ Get the next non-blank non-relax non-call token 430 ⟩ ≡
repeat *get_x_token*;
until (*cur_cmd* ≠ *spacer*) ∧ (*cur_cmd* ≠ *relax*)

This code is used in sections 429, 1254, 1260, 1327, 1336, 1387, 1402, and 1446.

431. The *scan_optional_equals* routine looks for an optional '=' sign preceded by optional spaces; '*\relax*' is not ignored here.

```

procedure scan_optional_equals;
  begin ⟨ Get the next non-blank non-call token 432 ⟩;
  if cur_tok ≠ other_token + "=" then back_input;
  end;

```

432. ⟨ Get the next non-blank non-call token 432 ⟩ ≡
repeat *get_x_token*;
until *cur_cmd* ≠ *spacer*

This code is used in sections 431, 467, 481, 529, 552, 604, 1221, 1766, 1781, and 1782.

433. In case you are getting bored, here is a slightly less trivial routine: Given a string of lowercase letters, like ‘pt’ or ‘plus’ or ‘width’, the *scan_keyword* routine checks to see whether the next tokens of input match this string. The match must be exact, except that uppercase letters will match their lowercase counterparts; uppercase equivalents are determined by subtracting “a” – “A”, rather than using the *uc_code* table, since TeX uses this routine only for its own limited set of keywords.

If a match is found, the characters are effectively removed from the input and *true* is returned. Otherwise *false* is returned, and the input is left essentially unchanged (except for the fact that some macros may have been expanded, etc.).

```
function scan_keyword(s : str_number): boolean; { look for a given string }
  label exit;
  var p: pointer; { tail of the backup list }
      q: pointer; { new node being added to the token list via store_new_token }
      k: pool_pointer; { index into str_pool }
      save_cur_cs: pointer; { to save cur_cs }
  begin p ← backup_head; link(p) ← null; k ← str_start[s]; save_cur_cs ← cur_cs;
  while k < str_start[s + 1] do
    begin get_x_token; { recursion is possible here }
    if (cur_cs = 0) ∧ ((cur_chr = so(str_pool[k])) ∨ (cur_chr = so(str_pool[k] – “a” + “A”)) then
      begin store_new_token(cur_tok); incr(k);
      end
    else if (cur_cmd ≠ spacer) ∨ (p ≠ backup_head) then
      begin back_input;
      if p ≠ backup_head then back_list(link(backup_head));
      cur_cs ← save_cur_cs; scan_keyword ← false; return;
      end;
    end;
  flush_list(link(backup_head)); scan_keyword ← true;
exit: end;
```

434. Here is a procedure that sounds an alarm when mu and non-mu units are being switched.

```
procedure mu_error;
  begin print_err("Incompatible glue units");
  help1("I'm going to assume that 1mu=1pt when they're mixed."); error;
  end;
```

435. The next routine ‘*scan_something_internal*’ is used to fetch internal numeric quantities like ‘\hsize’, and also to handle the ‘\the’ when expanding constructions like ‘\the\toks0’ and ‘\the\baselineskip’. Soon we will be considering the *scan_int* procedure, which calls *scan_something_internal*; on the other hand, *scan_something_internal* also calls *scan_int*, for constructions like ‘\catcode\’\$’ or ‘\fontdimen 3 \ff’. So we have to declare *scan_int* as a *forward* procedure. A few other procedures are also declared at this point.

```
procedure scan_int; forward; { scans an integer value }
⟨ Declare procedures that scan restricted classes of integers 459 ⟩
⟨ Declare ε-TeX procedures for scanning 1679 ⟩
⟨ Declare procedures that scan font-related stuff 604 ⟩
```

436. TeX doesn't know exactly what to expect when *scan_something_internal* begins. For example, an integer or dimension or glue value could occur immediately after '**\hskip**'; and one can even say '**\the**' with respect to token lists in constructions like '**\xdef\o{\the\output}**'. On the other hand, only integers are allowed after a construction like '**\count**'. To handle the various possibilities, *scan_something_internal* has a *level* parameter, which tells the "highest" kind of quantity that *scan_something_internal* is allowed to produce. Six levels are distinguished, namely *int_val*, *dimen_val*, *glue_val*, *mu_val*, *ident_val*, and *tok_val*.

The output of *scan_something_internal* (and of the other routines *scan_int*, *scan_dimen*, and *scan_glue* below) is put into the global variable *cur_val*, and its level is put into *cur_val_level*. The highest values of *cur_val_level* are special: *mu_val* is used only when *cur_val* points to something in a "muskip" register, or to one of the three parameters **\thinmuskip**, **\medmuskip**, **\thickmuskip**; *ident_val* is used only when *cur_val* points to a font identifier; *tok_val* is used only when *cur_val* points to *null* or to the reference count of a token list. The last two cases are allowed only when *scan_something_internal* is called with *level* = *tok_val*.

If the output is glue, *cur_val* will point to a glue specification, and the reference count of that glue will have been updated to reflect this reference; if the output is a nonempty token list, *cur_val* will point to its reference count, but in this case the count will not have been updated. Otherwise *cur_val* will contain the integer or scaled value in question.

```
define int_val = 0 { integer values }
define dimen_val = 1 { dimension values }
define glue_val = 2 { glue specifications }
define mu_val = 3 { math glue specifications }
define ident_val = 4 { font identifier }
define tok_val = 5 { token lists }
```

⟨ Global variables 13 ⟩ +=

```
cur_val: integer; { value returned by numeric scanners }
cur_val_level: int_val .. tok_val; { the "level" of this value }
```

437. The hash table is initialized with '**\count**', '**\dimen**', '**\skip**', and '**\muskip**' all having *register* as their command code; they are distinguished by the *chr_code*, which is either *int_val*, *dimen_val*, *glue_val*, or *mu_val* more than *mem_bot* (dynamic variable-size nodes cannot have these values)

⟨ Put each of TeX's primitives into the hash table 244 ⟩ +=

```
primitive("count", register, mem_bot + int_val); primitive("dimen", register, mem_bot + dimen_val);
primitive("skip", register, mem_bot + glue_val); primitive("muskip", register, mem_bot + mu_val);
```

438. ⟨ Cases of *print_cmd_chr* for symbolic printing of primitives 245 ⟩ +=

```
register: ⟨ Cases of register for print_cmd_chr 1829 ⟩;
```

439. OK, we're ready for *scan_something_internal* itself. A second parameter, *negative*, is set *true* if the value that is found should be negated. It is assumed that *cur_cmd* and *cur_chr* represent the first token of the internal quantity to be scanned; an error will be signalled if *cur_cmd* < *min_internal* or *cur_cmd* > *max_internal*.

```

define scanned_result_end(#)  $\equiv$  cur_val_level  $\leftarrow$  #; end
define scanned_result(#)  $\equiv$  begin cur_val  $\leftarrow$  #; scanned_result_end
procedure scan_something_internal(level : small_number; negative : boolean);
    { fetch an internal parameter }
label exit, restart;
var m: halfword; { chr_code part of the operand token }
    n, k: integer; { accumulators }
    q, r: pointer; { general purpose indices }
    tx: pointer; { effective tail node }
    i: four_quarters; { character info }
    p: 0 .. nest_size; { index into nest }
begin restart: m  $\leftarrow$  cur_chr;
case cur_cmd of
  def_code:  $\langle$  Fetch a character code from some table 440  $\rangle$ ;
  toks_register, assign_toks, def_family, set_font, def_font, letterspace_font, pdf_copy_font:  $\langle$  Fetch a token list
    or font identifier, provided that level = tok_val 441  $\rangle$ ;
  assign_int: scanned_result(eqtb[m].int)(int_val);
  assign_dimen: scanned_result(eqtb[m].sc)(dimen_val);
  assign_glue: scanned_result(equiv(m))(glue_val);
  assign_mu_glue: scanned_result(equiv(m))(mu_val);
  set_aux:  $\langle$  Fetch the space_factor or the prev_depth 444  $\rangle$ ;
  set_prev_graf:  $\langle$  Fetch the prev_graf 448  $\rangle$ ;
  set_page_int:  $\langle$  Fetch the dead_cycles or the insert_penalties 445  $\rangle$ ;
  set_page_dimen:  $\langle$  Fetch something on the page_so_far 447  $\rangle$ ;
  set_shape:  $\langle$  Fetch the par_shape size 449  $\rangle$ ;
  set_box_dimen:  $\langle$  Fetch a box dimension 446  $\rangle$ ;
  char_given, math_given: scanned_result(cur_chr)(int_val);
  assign_font_dimen:  $\langle$  Fetch a font dimension 451  $\rangle$ ;
  assign_font_int:  $\langle$  Fetch a font integer 452  $\rangle$ ;
  register:  $\langle$  Fetch a register 453  $\rangle$ ;
  last_item:  $\langle$  Fetch an item in the current node, if appropriate 450  $\rangle$ ;
  ignore_spaces: { trap unexpandable primitives }
    if cur_chr = 1 then  $\langle$  Reset cur_tok for unexpandable primitives, goto restart 395  $\rangle$ ;
    othercases  $\langle$  Complain that \the can't do this; give zero result 454  $\rangle$ 
endcases;
while cur_val_level > level do  $\langle$  Convert cur_val to a lower level 455  $\rangle$ ;
   $\langle$  Fix the reference count, if any, and negate cur_val if negative 456  $\rangle$ ;
exit: end;

```

```

440.  $\langle$  Fetch a character code from some table 440  $\rangle \equiv$ 
begin scan_char_num;
if m = math_code_base then scanned_result(ho(math_code(cur_val)))(int_val)
else if m < math_code_base then scanned_result(equiv(m + cur_val))(int_val)
  else scanned_result(eqtb[m + cur_val].int)(int_val);
end

```

This code is used in section 439.

```

441.  ⟨Fetch a token list or font identifier, provided that level = tok_val 441⟩ ≡
    if level ≠ tok_val then
      begin print_err("Missing_number, treated as zero");
      help3("A_number_should_have_been_here; I inserted `0'.")
      ("(If you can't figure out why I needed to see a number,")
      ("look up `weird_error' in the index to The TeXbook.)"); back_error;
      scanned_result(0)(dimen_val);
    end
    else if cur_cmd ≤ assign_toks then
      begin if cur_cmd < assign_toks then { cur_cmd = toks_register }
        if m = mem_bot then
          begin scan_register_num;
          if cur_val < 256 then cur_val ← equiv(toks_base + cur_val)
          else begin find_sa_element(tok_val, cur_val, false);
            if cur_ptr = null then cur_val ← null
            else cur_val ← sa_ptr(cur_ptr);
            end;
          end
          else cur_val ← sa_ptr(m)
        else cur_val ← equiv(m);
        cur_val_level ← tok_val;
      end
      else begin back_input; scan_font_ident; scanned_result(font_id_base + cur_val)(ident_val);
      end

```

This code is used in section 439.

442. Users refer to ‘`\the\spacefactor`’ only in horizontal mode, and to ‘`\the\prevdepth`’ only in vertical mode; so we put the associated mode in the modifier part of the `set_aux` command. The `set_page_int` command has modifier 0 or 1, for ‘`\deadcycles`’ and ‘`\insertpenalties`’, respectively. The `set_box_dimen` command is modified by either `width_offset`, `height_offset`, or `depth_offset`. And the `last_item` command is modified by either `int_val`, `dimen_val`, `glue_val`, `input_line_no_code`, or `badness_code`. pdfTeX adds the codes for its extensions: `pdftex_version_code`, ... ε -TeX inserts `last_node_type_code` after `glue_val` and adds the codes for its extensions: `eTeX_version_code`, ...

```

define last_node_type_code = glue_val + 1 { code for \lastnodetype }
define input_line_no_code = glue_val + 2 { code for \inputlineno }
define badness_code = input_line_no_code + 1 { code for \badness }

define pdftex_first_rint_code = badness_code + 1 { base for pdfTeX's command codes }
define pdftex_version_code = pdftex_first_rint_code + 0 { code for \pdftexversion }
define pdf_last_obj_code = pdftex_first_rint_code + 1 { code for \pdflastobj }
define pdf_last_xform_code = pdftex_first_rint_code + 2 { code for \pdflastxform }
define pdf_last_ximage_code = pdftex_first_rint_code + 3 { code for \pdflastximage }
define pdf_last_ximage_pages_code = pdftex_first_rint_code + 4 { code for \pdflastximagepages }
define pdf_last_annot_code = pdftex_first_rint_code + 5 { code for \pdflastannot }
define pdf_last_x_pos_code = pdftex_first_rint_code + 6 { code for \pdflastxpos }
define pdf_last_y_pos_code = pdftex_first_rint_code + 7 { code for \pdflastypos }
define pdf_retval_code = pdftex_first_rint_code + 8 { global multi-purpose return value }
define pdf_last_ximage_colordepth_code = pdftex_first_rint_code + 9
    { code for \pdflastximagecolordepth }
define elapsed_time_code = pdftex_first_rint_code + 10 { code for \pdfelapsedtime }
define pdf_shell_escape_code = pdftex_first_rint_code + 11 { code for \pdfshellescape }
define random_seed_code = pdftex_first_rint_code + 12 { code for \pdfrandomseed }
define pdf_last_link_code = pdftex_first_rint_code + 13 { code for \pdflastlink }
define pdftex_last_item_codes = pdftex_first_rint_code + 13 { end of pdfTeX's command codes }

define eTeX_int = pdftex_last_item_codes + 1 { first of  $\varepsilon$ -TeX codes for integers }
define eTeX_dim = eTeX_int + 8 { first of  $\varepsilon$ -TeX codes for dimensions }
define eTeX_glue = eTeX_dim + 9 { first of  $\varepsilon$ -TeX codes for glue }
define eTeX_mu = eTeX_glue + 1 { first of  $\varepsilon$ -TeX codes for muglue }
define eTeX_expr = eTeX_mu + 1 { first of  $\varepsilon$ -TeX codes for expressions }

```

(Put each of TeX's primitives into the hash table 244) +=

```

primitive("spacefactor", set_aux, hmode); primitive("prevdepth", set_aux, vmode);
primitive("deadcycles", set_page_int, 0); primitive("insertpenalties", set_page_int, 1);
primitive("wd", set_box_dimen, width_offset); primitive("ht", set_box_dimen, height_offset);
primitive("dp", set_box_dimen, depth_offset); primitive("lastpenalty", last_item, int_val);
primitive("lastkern", last_item, dimen_val); primitive("lastskip", last_item, glue_val);
primitive("inputlineno", last_item, input_line_no_code); primitive("badness", last_item, badness_code);
primitive("pdftexversion", last_item, pdftex_version_code);
primitive("pdflastobj", last_item, pdf_last_obj_code);
primitive("pdflastxform", last_item, pdf_last_xform_code);
primitive("pdflastximage", last_item, pdf_last_ximage_code);
primitive("pdflastximagepages", last_item, pdf_last_ximage_pages_code);
primitive("pdflastannot", last_item, pdf_last_annot_code);
primitive("pdflastxpos", last_item, pdf_last_x_pos_code);
primitive("pdflastypos", last_item, pdf_last_y_pos_code);
primitive("pdfretval", last_item, pdf_retval_code);
primitive("pdflastximagecolordepth", last_item, pdf_last_ximage_colordepth_code);
primitive("pdfelapsedtime", last_item, elapsed_time_code);
primitive("pdfshellescape", last_item, pdf_shell_escape_code);

```

```
primitive("pdfrandomseed", last_item, random_seed_code);
primitive("pdflastlink", last_item, pdf_last_link_code);
```

443. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
set_aux: if chr_code = vmode then print_esc("prevdepth") else print_esc("spacefactor");
set_page_int: if chr_code = 0 then print_esc("deadcycles")
   $\langle$  Cases of set_page_int for print_cmd_chr 1690  $\rangle$  else print_esc("insertpenalties");
set_box_dimen: if chr_code = width_offset then print_esc("wd")
  else if chr_code = height_offset then print_esc("ht")
    else print_esc("dp");
last_item: case chr_code of
  int_val: print_esc("lastpenalty");
  dimen_val: print_esc("lastkern");
  glue_val: print_esc("lastskip");
  input_line_no_code: print_esc("inputlineno");
   $\langle$  Cases of last_item for print_cmd_chr 1647  $\rangle$ 
  pdftex_version_code: print_esc("pdftexversion");
  pdf_last_obj_code: print_esc("pdflastobj");
  pdf_last_xform_code: print_esc("pdflastxform");
  pdf_last_ximage_code: print_esc("pdflastximage");
  pdf_last_ximage_pages_code: print_esc("pdflastximagepages");
  pdf_last_annot_code: print_esc("pdflastannot");
  pdf_last_x_pos_code: print_esc("pdflastxpos");
  pdf_last_y_pos_code: print_esc("pdflastypos");
  pdf_retval_code: print_esc("pdfretval");
  pdf_last_ximage_colordepth_code: print_esc("pdflastximagecolordepth");
  elapsed_time_code: print_esc("pdfelapsedtime");
  pdf_shell_escape_code: print_esc("pdfshellescape");
  random_seed_code: print_esc("pdfrandomseed");
  pdf_last_link_code: print_esc("pdflastlink");
  othercases print_esc("badness")
endcases;
```

444. \langle Fetch the *space_factor* or the *prev_depth* 444 $\rangle \equiv$

```
if abs(mode)  $\neq$  m then
  begin print_err("Improper_"); print_cmd_chr(set_aux, m);
  help4("You_can_refer_to_spacefactor_only_in_horizontal_mode;")
  ("you_can_refer_to_prevdepth_only_in_vertical_mode;_and")
  ("neither_of_these_is_meaningful_inside_write_So")
  ("I'm_forgetting_what_you_said_and_using_zero_instead."); error;
  if level  $\neq$  tok_val then scanned_result(0)(dimen_val)
  else scanned_result(0)(int_val);
  end
else if m = vmode then scanned_result(prev_depth)(dimen_val)
  else scanned_result(space_factor)(int_val)
```

This code is used in section 439.

This code is used in section 439.

This code is used in section 439.

447. Inside an `\output` routine, a user may wish to look at the page totals that were present at the moment when output was triggered.

This code is used in section 439.

This code is used in section [439](#).

This code is used in section 439.

450. Here is where `\lastpenalty`, `\lastkern`, `\lastskip`, and `\lastnodetype` are implemented. The reference count for `\lastskip` will be updated later.

We also handle `\inputlineno` and `\badness` here, because they are legal in similar contexts.

The macro `find_effective_tail_eTeX` sets `tx` to the last non-`\endM` node of the current list.

```

define find_effective_tail_eTeX  $\equiv tx \leftarrow tail;$ 
  if  $\neg is\_char\_node(tx)$  then
    if  $(type(tx) = math\_node) \wedge (subtype(tx) = end\_M\_code)$  then
      begin  $r \leftarrow head;$ 
      repeat  $q \leftarrow r; r \leftarrow link(q);$ 
      until  $r = tx;$ 
       $tx \leftarrow q;$ 
    end
  define find_effective_tail  $\equiv find\_effective\_tail\_eTeX$ 
   $\langle$  Fetch an item in the current node, if appropriate 450  $\rangle \equiv$ 
  if  $m \geq input\_line\_no\_code$  then
    if  $m \geq eTeX\_glue$  then  $\langle$  Process an expression and return 1777  $\rangle$ 
  else if  $m \geq eTeX\_dim$  then
    begin case  $m$  of
       $\langle$  Cases for fetching a dimension value 1668  $\rangle$ 
    end;  $\{$  there are no other cases  $\}$ 
     $cur\_val\_level \leftarrow dimen\_val;$ 
  end
  else begin case  $m$  of
    input_line_no_code:  $cur\_val \leftarrow line;$ 
    badness_code:  $cur\_val \leftarrow last\_badness;$ 
    pdfTeX_version_code:  $cur\_val \leftarrow pdfTeX\_version;$ 
    pdf_last_obj_code:  $cur\_val \leftarrow pdf\_last\_obj;$ 
    pdf_last_xform_code:  $cur\_val \leftarrow pdf\_last\_xform;$ 
    pdf_last_ximage_code:  $cur\_val \leftarrow pdf\_last\_ximage;$ 
    pdf_last_ximage_pages_code:  $cur\_val \leftarrow pdf\_last\_ximage\_pages;$ 
    pdf_last_annot_code:  $cur\_val \leftarrow pdf\_last\_annot;$ 
    pdf_last_x_pos_code:  $cur\_val \leftarrow pdf\_last\_x\_pos;$ 
    pdf_last_y_pos_code:  $cur\_val \leftarrow pdf\_last\_y\_pos;$ 
    pdf_retval_code:  $cur\_val \leftarrow pdf\_retval;$ 
    pdf_last_ximage_colordepth_code:  $cur\_val \leftarrow pdf\_last\_ximage\_colordepth;$ 
    elapsed_time_code:  $cur\_val \leftarrow get\_microinterval;$ 
    random_seed_code:  $cur\_val \leftarrow random\_seed;$ 
    pdf_shell_escape_code: begin if shellenabledp then
      begin if restrictedshell then  $cur\_val \leftarrow 2$ 
      else  $cur\_val \leftarrow 1;$ 
    end
    else  $cur\_val \leftarrow 0;$ 
  end;
    pdf_last_link_code:  $cur\_val \leftarrow pdf\_last\_link;$ 
     $\langle$  Cases for fetching an integer value 1648  $\rangle$ 
  end;  $\{$  there are no other cases  $\}$ 
   $cur\_val\_level \leftarrow int\_val;$ 
  end
  else begin if  $cur\_chr = glue\_val$  then  $cur\_val \leftarrow zero\_glue$  else  $cur\_val \leftarrow 0;$ 
    find_effective_tail;
  if  $cur\_chr = last\_node\_type\_code$  then
    begin  $cur\_val\_level \leftarrow int\_val;$ 

```

```

if ( $tx = head$ )  $\vee$  ( $mode = 0$ ) then  $cur\_val \leftarrow -1$ ;
end
else  $cur\_val\_level \leftarrow cur\_chr$ ;
if  $\neg is\_char\_node(tx) \wedge (mode \neq 0)$  then
  case  $cur\_chr$  of
     $int\_val$ : if  $type(tx) = penalty\_node$  then  $cur\_val \leftarrow penalty(tx)$ ;
     $dimen\_val$ : if  $type(tx) = kern\_node$  then  $cur\_val \leftarrow width(tx)$ ;
     $glue\_val$ : if  $type(tx) = glue\_node$  then
      begin  $cur\_val \leftarrow glue\_ptr(tx)$ ;
      if  $subtype(tx) = mu\_glue$  then  $cur\_val\_level \leftarrow mu\_val$ ;
      end;
     $last\_node\_type\_code$ : if  $type(tx) \leq unset\_node$  then  $cur\_val \leftarrow type(tx) + 1$ 
      else  $cur\_val \leftarrow unset\_node + 2$ ;
    end { there are no other cases }
  else if ( $mode = vmode$ )  $\wedge$  ( $tx = head$ ) then
    case  $cur\_chr$  of
       $int\_val$ :  $cur\_val \leftarrow last\_penalty$ ;
       $dimen\_val$ :  $cur\_val \leftarrow last\_kern$ ;
       $glue\_val$ : if  $last\_glue \neq max\_halfword$  then  $cur\_val \leftarrow last\_glue$ ;
       $last\_node\_type\_code$ :  $cur\_val \leftarrow last\_node\_type$ ;
      end; { there are no other cases }
    end
end

```

This code is used in section 439.

451. \langle Fetch a font dimension 451 $\rangle \equiv$

```

begin  $find\_font\_dimen(false)$ ;  $font\_info[fmem\_ptr].sc \leftarrow 0$ ;
 $scanned\_result(font\_info[cur\_val].sc)(dimen\_val)$ ;
end

```

This code is used in section 439.

452. \langle Fetch a font integer 452 $\rangle \equiv$

```

begin  $scan\_font\_ident$ ;
if  $m = 0$  then  $scanned\_result(hyphen\_char[cur\_val])(int\_val)$ 
else if  $m = 1$  then  $scanned\_result(skew\_char[cur\_val])(int\_val)$ 
else if  $m = no\_lig\_code$  then  $scanned\_result(test\_no\_ligatures(cur\_val))(int\_val)$ 
else begin  $n \leftarrow cur\_val$ ;  $scan\_char\_num$ ;  $k \leftarrow cur\_val$ ;
  case  $m$  of
     $lp\_code\_base$ :  $scanned\_result(get\_lp\_code(n, k))(int\_val)$ ;
     $rp\_code\_base$ :  $scanned\_result(get\_rp\_code(n, k))(int\_val)$ ;
     $ef\_code\_base$ :  $scanned\_result(get\_ef\_code(n, k))(int\_val)$ ;
     $tag\_code$ :  $scanned\_result(get\_tag\_code(n, k))(int\_val)$ ;
     $kn\_bs\_code\_base$ :  $scanned\_result(get\_kn\_bs\_code(n, k))(int\_val)$ ;
     $st\_bs\_code\_base$ :  $scanned\_result(get\_st\_bs\_code(n, k))(int\_val)$ ;
     $sh\_bs\_code\_base$ :  $scanned\_result(get\_sh\_bs\_code(n, k))(int\_val)$ ;
     $kn\_bc\_code\_base$ :  $scanned\_result(get\_kn\_bc\_code(n, k))(int\_val)$ ;
     $kn\_ac\_code\_base$ :  $scanned\_result(get\_kn\_ac\_code(n, k))(int\_val)$ ;
  end;
end;
end

```

This code is used in section 439.

453. \langle Fetch a register 453 $\rangle \equiv$

```

begin if ( $m < mem\_bot$ )  $\vee$  ( $m > lo\_mem\_stat\_max$ ) then
  begin  $cur\_val\_level \leftarrow sa\_type(m)$ ;
  if  $cur\_val\_level < glue\_val$  then  $cur\_val \leftarrow sa\_int(m)$ 
  else  $cur\_val \leftarrow sa\_ptr(m)$ ;
  end
else begin  $scan\_register\_num$ ;  $cur\_val\_level \leftarrow m - mem\_bot$ ;
  if  $cur\_val > 255$  then
    begin  $find\_sa\_element(cur\_val\_level, cur\_val, false)$ ;
    if  $cur\_ptr = null$  then
      if  $cur\_val\_level < glue\_val$  then  $cur\_val \leftarrow 0$ 
      else  $cur\_val \leftarrow zero\_glue$ 
    else if  $cur\_val\_level < glue\_val$  then  $cur\_val \leftarrow sa\_int(cur\_ptr)$ 
    else  $cur\_val \leftarrow sa\_ptr(cur\_ptr)$ ;
    end
  else case  $cur\_val\_level$  of
     $int\_val$ :  $cur\_val \leftarrow count(cur\_val)$ ;
     $dimen\_val$ :  $cur\_val \leftarrow dimen(cur\_val)$ ;
     $glue\_val$ :  $cur\_val \leftarrow skip(cur\_val)$ ;
     $mu\_val$ :  $cur\_val \leftarrow mu\_skip(cur\_val)$ ;
  end; { there are no other cases }
  end;
end

```

This code is used in section 439.

454. \langle Complain that \the can't do this; give zero result 454 $\rangle \equiv$

```

begin  $print\_err("You\_can't\_use\_")$ ;  $print\_cmd\_chr(cur\_cmd, cur\_chr)$ ;  $print("\_after\_")$ ;
 $print\_esc("the")$ ;  $help1("I'm\_forgetting\_what\_you\_said\_and\_using\_zero\_instead.")$ ;  $error$ ;
if  $level \neq tok\_val$  then  $scanned\_result(0)(dimen\_val)$ 
else  $scanned\_result(0)(int\_val)$ ;
end

```

This code is used in section 439.

455. When a *glue_val* changes to a *dimen_val*, we use the width component of the glue; there is no need to decrease the reference count, since it has not yet been increased. When a *dimen_val* changes to an *int_val*, we use scaled points so that the value doesn't actually change. And when a *mu_val* changes to a *glue_val*, the value doesn't change either.

\langle Convert *cur_val* to a lower level 455 $\rangle \equiv$

```

begin if  $cur\_val\_level = glue\_val$  then  $cur\_val \leftarrow width(cur\_val)$ 
else if  $cur\_val\_level = mu\_val$  then  $mu\_error$ ;
   $decr(cur\_val\_level)$ ;
end

```

This code is used in section 439.

456. If *cur_val* points to a glue specification at this point, the reference count for the glue does not yet include the reference by *cur_val*. If *negative* is *true*, *cur_val_level* is known to be $\leq mu_val$.

\langle Fix the reference count, if any, and negate *cur_val* if *negative* 456 $\rangle \equiv$

```

if negative then
  if cur_val_level  $\geq$  glue_val then
    begin cur_val  $\leftarrow$  new_spec(cur_val);  $\langle$  Negate all three glue components of cur_val 457  $\rangle$ ;
    end
  else negate(cur_val)
else if (cur_val_level  $\geq$  glue_val)  $\wedge$  (cur_val_level  $\leq$  mu_val) then add_glue_ref(cur_val)

```

This code is used in section 439.

457. \langle Negate all three glue components of *cur_val* 457 $\rangle \equiv$

```

begin negate(width(cur_val)); negate(stretch(cur_val)); negate(shrink(cur_val));
end

```

This code is used in sections 456 and 1777.

458. Our next goal is to write the *scan_int* procedure, which scans anything that TeX treats as an integer. But first we might as well look at some simple applications of *scan_int* that have already been made inside of *scan_something_internal*.

459. \langle Declare procedures that scan restricted classes of integers 459 $\rangle \equiv$

```

procedure scan_eight_bit_int;
begin scan_int;
if (cur_val  $<$  0)  $\vee$  (cur_val  $>$  255) then
  begin print_err("Bad_register_code");
  help2("A_register_number_must_be_between_0_and_255.")
  ("I_changed_this_one_to_zero."); int_error(cur_val); cur_val  $\leftarrow$  0;
  end;
end;

```

See also sections 460, 461, 462, 463, and 1808.

This code is used in section 435.

460. \langle Declare procedures that scan restricted classes of integers 459 $\rangle + \equiv$

```

procedure scan_char_num;
begin scan_int;
if (cur_val  $<$  0)  $\vee$  (cur_val  $>$  255) then
  begin print_err("Bad_character_code");
  help2("A_character_number_must_be_between_0_and_255.")
  ("I_changed_this_one_to_zero."); int_error(cur_val); cur_val  $\leftarrow$  0;
  end;
end;

```

461. While we're at it, we might as well deal with similar routines that will be needed later.

⟨Declare procedures that scan restricted classes of integers 459⟩ +≡

```
procedure scan_four_bit_int;
begin scan_int;
if (cur_val < 0) ∨ (cur_val > 15) then
  begin print_err("Bad_number");
    help2("Since I expected to read a number between 0 and 15,")
    ("I changed this one to zero."); int_error(cur_val); cur_val ← 0;
  end;
end;
```

462. ⟨Declare procedures that scan restricted classes of integers 459⟩ +≡

```
procedure scan_fifteen_bit_int;
begin scan_int;
if (cur_val < 0) ∨ (cur_val > '77777) then
  begin print_err("Bad_mathchar"); help2("A mathchar number must be between 0 and 32767.")
    ("I changed this one to zero."); int_error(cur_val); cur_val ← 0;
  end;
end;
```

463. ⟨Declare procedures that scan restricted classes of integers 459⟩ +≡

```
procedure scan_twenty_seven_bit_int;
begin scan_int;
if (cur_val < 0) ∨ (cur_val > '77777777) then
  begin print_err("Bad_delimiter_code");
    help2("A numeric delimiter code must be between 0 and 227-1.")
    ("I changed this one to zero."); int_error(cur_val); cur_val ← 0;
  end;
end;
```

464. An integer number can be preceded by any number of spaces and '+' or '-' signs. Then comes either a decimal constant (i.e., radix 10), an octal constant (i.e., radix 8, preceded by '~'), a hexadecimal constant (radix 16, preceded by '"'), an alphabetic constant (preceded by '^'), or an internal variable. After scanning is complete, *cur_val* will contain the answer, which must be at most $2^{31} - 1 = 2147483647$ in absolute value. The value of *radix* is set to 10, 8, or 16 in the cases of decimal, octal, or hexadecimal constants, otherwise *radix* is set to zero. An optional space follows a constant.

```
define octal_token = other_token + "~" { apostrophe, indicates an octal constant }
define hex_token = other_token + "\"" { double quote, indicates a hex constant }
define alpha_token = other_token + "^" { reverse apostrophe, precedes alpha constants }
define point_token = other_token + "." { decimal point }
define continental_point_token = other_token + "," { decimal point, Eurostyle }
```

⟨Global variables 13⟩ +≡

radix: *small_number*; { *scan_int* sets this to 8, 10, 16, or zero }

465. We initialize the following global variables just in case *expand* comes into action before any of the basic scanning routines has assigned them a value.

⟨Set initial values of key variables 21⟩ +≡

```
cur_val ← 0; cur_val_level ← int_val; radix ← 0; cur_order ← normal;
```

466. The *scan_int* routine is used also to scan the integer part of a fraction; for example, the ‘3’ in ‘3.14159’ will be found by *scan_int*. The *scan_dimen* routine assumes that *cur_tok* = *point_token* after the integer part of such a fraction has been scanned by *scan_int*, and that the decimal point has been backed up to be scanned again.

```
procedure scan_int; { sets cur_val to an integer }
  label done, restart;
  var negative: boolean; { should the answer be negated? }
      m: integer; {  $2^{31}$  div radix, the threshold of danger }
      d: small_number; { the digit just scanned }
      vacuous: boolean; { have no digits appeared? }
      OK_so_far: boolean; { has an error message been issued? }
  begin radix  $\leftarrow$  0; OK_so_far  $\leftarrow$  true;
  < Get the next non-blank non-sign token; set negative appropriately 467 >;
  restart: if cur_tok = alpha_token then < Scan an alphabetic character code into cur_val 468 >
  else if cur_tok = cs_token_flag + frozen_primitive then
    < Reset cur_tok for unexpandable primitives, goto restart 395 >
  else if (cur_cmd  $\geq$  min_internal)  $\wedge$  (cur_cmd  $\leq$  max_internal) then
    scan_something_internal(int_val, false)
  else < Scan a numeric constant 470 >;
  if negative then negate(cur_val);
end;
```

467. < Get the next non-blank non-sign token; set *negative* appropriately 467 > \equiv
negative \leftarrow *false*;
repeat < Get the next non-blank non-call token 432 >;
 if *cur_tok* = *other_token* + "-" **then**
 begin *negative* \leftarrow \neg *negative*; *cur_tok* \leftarrow *other_token* + "+";
 end;
until *cur_tok* \neq *other_token* + "+"

This code is used in sections 466, 474, and 487.

468. A space is ignored after an alphabetic character constant, so that such constants behave like numeric ones.

```
< Scan an alphabetic character code into cur_val 468 >  $\equiv$ 
begin get_token; { suppress macro expansion }
if cur_tok < cs_token_flag then
  begin cur_val  $\leftarrow$  cur_chr;
  if cur_cmd  $\leq$  right_brace then
    if cur_cmd = right_brace then incr(align_state)
    else decr(align_state);
  end
else if cur_tok < cs_token_flag + single_base then cur_val  $\leftarrow$  cur_tok - cs_token_flag - active_base
else cur_val  $\leftarrow$  cur_tok - cs_token_flag - single_base;
if cur_val > 255 then
  begin print_err("Improper_alphabetic_constant");
  help2("A_one-character_control_sequence_belongs_after_a_`_mark.")
  ("So_I`m_essentially_inserting_0_here."); cur_val  $\leftarrow$  "0"; back_error;
  end
else < Scan an optional space 469 >;
end
```

This code is used in section 466.

469. \langle Scan an optional space 469 $\rangle \equiv$
begin *get_x_token*;
if *cur_cmd* \neq *spacer* **then** *back_input*;
end

This code is used in sections 468, 474, 481, 705, 1376, 1542, 1554, 1554, 1556, and 1563.

470. \langle Scan a numeric constant 470 $\rangle \equiv$
begin *radix* \leftarrow 10; *m* \leftarrow 214748364;
if *cur_tok* = *octal_token* **then**
 begin *radix* \leftarrow 8; *m* \leftarrow '2000000000; *get_x_token*;
 end
else if *cur_tok* = *hex_token* **then**
 begin *radix* \leftarrow 16; *m* \leftarrow '1000000000; *get_x_token*;
 end;
vacuous \leftarrow *true*; *cur_val* \leftarrow 0;
 \langle Accumulate the constant until *cur_tok* is not a suitable digit 471 \rangle ;
if *vacuous* **then** \langle Express astonishment that no number was here 472 \rangle
else if *cur_cmd* \neq *spacer* **then** *back_input*;
end

This code is used in section 466.

471. **define** *infinity* \equiv '17777777777 { the largest positive value that TeX knows }
define *zero_token* = *other_token* + "0" { zero, the smallest digit }
define *A_token* = *letter_token* + "A" { the smallest special hex digit }
define *other_A_token* = *other_token* + "A" { special hex digit of type *other_char* }
 \langle Accumulate the constant until *cur_tok* is not a suitable digit 471 $\rangle \equiv$
loop begin if (*cur_tok* < *zero_token* + *radix*) \wedge (*cur_tok* \geq *zero_token*) \wedge (*cur_tok* \leq *zero_token* + 9)
 then *d* \leftarrow *cur_tok* - *zero_token*
else if *radix* = 16 **then**
 if (*cur_tok* \leq *A_token* + 5) \wedge (*cur_tok* \geq *A_token*) **then** *d* \leftarrow *cur_tok* - *A_token* + 10
 else if (*cur_tok* \leq *other_A_token* + 5) \wedge (*cur_tok* \geq *other_A_token*) **then**
 d \leftarrow *cur_tok* - *other_A_token* + 10
 else goto *done*
 else goto *done*;
vacuous \leftarrow *false*;
if (*cur_val* \geq *m*) \wedge ((*cur_val* > *m*) \vee (*d* > 7) \vee (*radix* \neq 10)) **then**
 begin if *OK_so_far* **then**
 begin *print_err*("Number too big");
 help2("I can only go up to 2147483647='17777777777='7FFFFFFF,")
 ("so I'm using that number instead of yours."); *error*; *cur_val* \leftarrow *infinity*;
 OK_so_far \leftarrow *false*;
 end;
 end
 else *cur_val* \leftarrow *cur_val* * *radix* + *d*;
 get_x_token;
 end;
done:

This code is used in section 470.

472. \langle Express astonishment that no number was here 472 $\rangle \equiv$

```

begin print_err("Missing_number, treated as zero");
help3("A number should have been here; I inserted `0`.")
("If you can't figure out why I needed to see a number,")
("look up `weird_error` in the index to The TeXbook."); back_error;
end

```

This code is used in section 470.

473. The *scan_dimen* routine is similar to *scan_int*, but it sets *cur_val* to a *scaled* value, i.e., an integral number of sp. One of its main tasks is therefore to interpret the abbreviations for various kinds of units and to convert measurements to scaled points.

There are three parameters: *mu* is *true* if the finite units must be ‘mu’, while *mu* is *false* if ‘mu’ units are disallowed; *inf* is *true* if the infinite units ‘fil’, ‘fill’, ‘filll’ are permitted; and *shortcut* is *true* if *cur_val* already contains an integer and only the units need to be considered.

The order of infinity that was found in the case of infinite glue is returned in the global variable *cur_order*.

\langle Global variables 13 $\rangle + \equiv$

```

cur_order: glue_ord; { order of infinity found by scan_dimen }

```


474. Constructions like ‘-77 pt’ are legal dimensions, so *scan_dimen* may begin with *scan_int*. This explains why it is convenient to use *scan_int* also for the integer part of a decimal fraction.

Several branches of *scan_dimen* work with *cur_val* as an integer and with an auxiliary fraction *f*, so that the actual quantity of interest is $cur_val + f/2^{16}$. At the end of the routine, this “unpacked” representation is put into the single word *cur_val*, which suddenly switches significance from *integer* to *scaled*.

```

define attach_fraction = 88 { go here to pack cur_val and f into cur_val }
define attach_sign = 89 { go here when cur_val is correct except perhaps for sign }
define scan_normal_dimen  $\equiv$  scan_dimen(false, false, false)

procedure scan_dimen(mu, inf, shortcut : boolean); { sets cur_val to a dimension }
label done, done1, done2, found, not_found, attach_fraction, attach_sign;
var negative: boolean; { should the answer be negated? }
    f: integer; { numerator of a fraction whose denominator is  $2^{16}$  }
    { Local variables for dimension calculations 476 }
begin f  $\leftarrow$  0; arith_error  $\leftarrow$  false; cur_order  $\leftarrow$  normal; negative  $\leftarrow$  false;
if  $\neg$ shortcut then
    begin { Get the next non-blank non-sign token; set negative appropriately 467 };
    if (cur_cmd  $\geq$  min_internal)  $\wedge$  (cur_cmd  $\leq$  max_internal) then
        { Fetch an internal dimension and goto attach_sign, or fetch an internal integer 475 }
    else begin back_input;
        if cur_tok = continental_point_token then cur_tok  $\leftarrow$  point_token;
        if cur_tok  $\neq$  point_token then scan_int
        else begin radix  $\leftarrow$  10; cur_val  $\leftarrow$  0;
            end;
        if cur_tok = continental_point_token then cur_tok  $\leftarrow$  point_token;
        if (radix = 10)  $\wedge$  (cur_tok = point_token) then { Scan decimal fraction 478 };
        end;
    end;
if cur_val < 0 then { in this case f = 0 }
    begin negative  $\leftarrow$   $\neg$ negative; negate(cur_val);
    end;
    { Scan units and set cur_val to  $x \cdot (cur\_val + f/2^{16})$ , where there are x sp per unit; goto attach_sign if
      the units are internal 479 };
    { Scan an optional space 469 };
attach_sign: if arith_error  $\vee$  (abs(cur_val)  $\geq$  '10000000000) then
    { Report that this dimension is out of range 486 };
    if negative then negate(cur_val);
end;

```

475. { Fetch an internal dimension and **goto** *attach_sign*, or fetch an internal integer 475 } \equiv

```

if mu then
    begin scan_something_internal(mu_val, false); { Coerce glue to a dimension 477 };
    if cur_val_level = mu_val then goto attach_sign;
    if cur_val_level  $\neq$  int_val then mu_error;
    end
else begin scan_something_internal(dimen_val, false);
    if cur_val_level = dimen_val then goto attach_sign;
    end

```

This code is used in section 474.

476. \langle Local variables for dimension calculations 476 $\rangle \equiv$
num, denom: 1 .. 65536; { conversion ratio for the scanned units }
k, kk: *small_number*; { number of digits in a decimal fraction }
p, q: *pointer*; { top of decimal digit stack }
v: *scaled*; { an internal dimension }
save_cur_val: *integer*; { temporary storage of *cur_val* }

This code is used in section 474.

477. The following code is executed when *scan_something_internal* was called asking for *mu_val*, when we really wanted a “mudimen” instead of “muglue.”

\langle Coerce glue to a dimension 477 $\rangle \equiv$
if *cur_val_level* \geq *glue_val* **then**
 begin *v* \leftarrow *width*(*cur_val*); *delete_glue_ref*(*cur_val*); *cur_val* \leftarrow *v*;
end

This code is used in sections 475 and 481.

478. When the following code is executed, we have *cur_tok* = *point_token*, but this token has been backed up using *back_input*; we must first discard it.

It turns out that a decimal point all by itself is equivalent to ‘0.0’. Let’s hope people don’t use that fact.

\langle Scan decimal fraction 478 $\rangle \equiv$
begin *k* \leftarrow 0; *p* \leftarrow *null*; *get_token*; { *point_token* is being re-scanned }
loop begin *get_x_token*;
 if (*cur_tok* > *zero_token* + 9) \vee (*cur_tok* < *zero_token*) **then goto** *done1*;
 if *k* < 17 **then** { digits for *k* \geq 17 cannot affect the result }
 begin *q* \leftarrow *get_avail*; *link*(*q*) \leftarrow *p*; *info*(*q*) \leftarrow *cur_tok* - *zero_token*; *p* \leftarrow *q*; *incr*(*k*);
 end;
 end;
done1: **for** *kk* \leftarrow *k* **downto** 1 **do**
 begin *dig*[*kk* - 1] \leftarrow *info*(*p*); *q* \leftarrow *p*; *p* \leftarrow *link*(*p*); *free_avail*(*q*);
 end;
 f \leftarrow *round_decimals*(*k*);
if *cur_cmd* \neq *spacer* **then** *back_input*;
end

This code is used in section 474.

479. Now comes the harder part: At this point in the program, *cur_val* is a nonnegative integer and $f/2^{16}$ is a nonnegative fraction less than 1; we want to multiply the sum of these two quantities by the appropriate factor, based on the specified units, in order to produce a *scaled* result, and we want to do the calculation with fixed point arithmetic that does not overflow.

```

<Scan units and set cur_val to  $x \cdot (cur\_val + f/2^{16})$ , where there are  $x$  sp per unit; goto attach_sign if the
  units are internal 479>  $\equiv$ 
if inf then <Scan for fil units; goto attach_fraction if found 480>;
<Scan for units that are internal dimensions; goto attach_sign with cur_val set if found 481>;
if mu then <Scan for mu units and goto attach_fraction 482>;
if scan_keyword("true") then <Adjust for the magnification ratio 483>;
if scan_keyword("pt") then goto attach_fraction; {the easy case}
<Scan for all other units and adjust cur_val and f accordingly; goto done in the case of scaled
  points 484>;
attach_fraction: if cur_val  $\geq$  '40000 then arith_error  $\leftarrow$  true
  else cur_val  $\leftarrow$  cur_val * unity + f;
done:

```

This code is used in section 474.

480. A specification like 'fillllll' or 'fill L L L' will lead to two error messages (one for each additional keyword "l").

```

<Scan for fil units; goto attach_fraction if found 480>  $\equiv$ 
if scan_keyword("fil") then
  begin cur_order  $\leftarrow$  fil;
  while scan_keyword("l") do
    begin if cur_order = filll then
      begin print_err("Illegal_unit_of_measure_"); print("replaced_by_filll");
      help1("I_dddon't_go_any_higher_than_filll."); error;
      end
    else incr(cur_order);
    end;
  goto attach_fraction;
end

```

This code is used in section 479.

481. \langle Scan for units that are internal dimensions; **goto** *attach_sign* with *cur_val* set if found 481 $\rangle \equiv$
save_cur_val \leftarrow *cur_val*; \langle Get the next non-blank non-call token 432 \rangle ;
if (*cur_cmd* < *min_internal*) \vee (*cur_cmd* > *max_internal*) **then** *back_input*
else begin if *mu* **then**
 begin *scan_something_internal*(*mu_val*, *false*); \langle Coerce glue to a dimension 477 \rangle ;
 if *cur_val_level* \neq *mu_val* **then** *mu_error*;
 end
 else *scan_something_internal*(*dimen_val*, *false*);
 v \leftarrow *cur_val*; **goto** *found*;
 end;
if *mu* **then goto** *not_found*;
if *scan_keyword*("em") **then** *v* \leftarrow (\langle The em width for *cur_font* 584 \rangle)
else if *scan_keyword*("ex") **then** *v* \leftarrow (\langle The x-height for *cur_font* 585 \rangle)
 else if *scan_keyword*("px") **then** *v* \leftarrow *pdf_px_dimen*
 else goto *not_found*;
 \langle Scan an optional space 469 \rangle ;
found: *cur_val* \leftarrow *nx_plus_y*(*save_cur_val*, *v*, *xn_over_d*(*v*, *f*, '200000')); **goto** *attach_sign*;
not_found:

This code is used in section 479.

482. \langle Scan for mu units and **goto** *attach_fraction* 482 $\rangle \equiv$
if *scan_keyword*("mu") **then goto** *attach_fraction*
else begin *print_err*("Illegal unit of measurement"); *print*("mu inserted");
 help4("The unit of measurement in math glue must be mu.")
 ("To recover gracefully from this error, it's best to")
 ("delete the erroneous units; e.g., type `2' to delete")
 ("two letters. (See Chapter 27 of The TeXbook.)"); *error*; **goto** *attach_fraction*;
end

This code is used in section 479.

483. \langle Adjust for the magnification ratio 483 $\rangle \equiv$
begin *prepare_mag*;
if *mag* \neq 1000 **then**
 begin *cur_val* \leftarrow *xn_over_d*(*cur_val*, 1000, *mag*); *f* \leftarrow (1000 * *f* + '200000 * remainder) **div** *mag*;
 cur_val \leftarrow *cur_val* + (*f* **div** '200000); *f* \leftarrow *f* **mod** '200000;
 end;
end

This code is used in section 479.

484. The necessary conversion factors can all be specified exactly as fractions whose numerator and denominator sum to 32768 or less. According to the definitions here, $2660\text{ dd} \approx 1000.33297\text{ mm}$; this agrees well with the value 1000.333 mm cited by Bosshard in *Technische Grundlagen zur Satzherstellung* (Bern, 1980). The Didot point has been newly standardized in 1978; it's now exactly $1\text{ nd} = 0.375\text{ mm}$. Conversion uses the equation $0.375 = 21681/20320/72.27 \cdot 25.4$. The new Cicero follows the new Didot point; $1\text{ nc} = 12\text{ nd}$. These would lead to the ratios $21681/20320$ and $65043/5080$, respectively. The closest approximations supported by the algorithm would be $11183/10481$ and $1370/107$. In order to maintain the relation $1\text{ nc} = 12\text{ nd}$, we pick the ratio $685/642$ for nd , however.

```

define set_conversion_end(#)  $\equiv$  denom  $\leftarrow$  #;
end
define set_conversion(#)  $\equiv$  begin num  $\leftarrow$  #; set_conversion_end
<Scan for all other units and adjust cur_val and f accordingly; goto done in the case of scaled points 484>  $\equiv$ 
if scan_keyword("in") then set_conversion(7227)(100)
else if scan_keyword("pc") then set_conversion(12)(1)
else if scan_keyword("cm") then set_conversion(7227)(254)
else if scan_keyword("mm") then set_conversion(7227)(2540)
else if scan_keyword("bp") then set_conversion(7227)(7200)
else if scan_keyword("dd") then set_conversion(1238)(1157)
else if scan_keyword("cc") then set_conversion(14856)(1157)
else if scan_keyword("nd") then set_conversion(685)(642)
else if scan_keyword("nc") then set_conversion(1370)(107)
else if scan_keyword("sp") then goto done
else <Complain about unknown unit and goto done2 485>;
cur_val  $\leftarrow$  xn_over_d(cur_val, num, denom); f  $\leftarrow$  (num * f + '200000 * remainder) div denom;
cur_val  $\leftarrow$  cur_val + (f div '200000); f  $\leftarrow$  f mod '200000;
done2:

```

This code is used in section 479.

```

485. <Complain about unknown unit and goto done2 485>  $\equiv$ 
begin print_err("Illegal unit of measure"); print("pt inserted");
help6("Dimensions can be in units of em, ex, in, pt, pc,")
("cm, mm, dd, cc, nd, nc, bp, or sp; but yours is a new one!")
("I'll assume that you meant to say pt, for printer's points.")
("To recover gracefully from this error, it's best to")
("delete the erroneous units; e.g., type `2' to delete")
("two letters. (See Chapter 27 of The TeXbook.)"); error; goto done2;
end

```

This code is used in section 484.

```

486. <Report that this dimension is out of range 486>  $\equiv$ 
begin print_err("Dimension too large");
help2("I can't work with sizes bigger than about 19 feet.")
("Continue and I'll use the largest value I can.");
error; cur_val  $\leftarrow$  max_dimen; arith_error  $\leftarrow$  false;
end

```

This code is used in section 474.

487. The final member of TeX's value-scanning trio is *scan_glue*, which makes *cur_val* point to a glue specification. The reference count of that glue spec will take account of the fact that *cur_val* is pointing to it.

The *level* parameter should be either *glue_val* or *mu_val*.

Since *scan_dimen* was so much more complex than *scan_int*, we might expect *scan_glue* to be even worse. But fortunately, it is very simple, since most of the work has already been done.

```
procedure scan_glue(level : small_number); { sets cur_val to a glue spec pointer }
  label exit;
  var negative: boolean; { should the answer be negated? }
      q: pointer; { new glue specification }
      mu: boolean; { does level = mu_val? }
  begin mu  $\leftarrow$  (level = mu_val);  $\langle$  Get the next non-blank non-sign token; set negative appropriately 467  $\rangle$ ;
  if (cur_cmd  $\geq$  min_internal)  $\wedge$  (cur_cmd  $\leq$  max_internal) then
    begin scan_something_internal(level, negative);
    if cur_val_level  $\geq$  glue_val then
      begin if cur_val_level  $\neq$  level then mu_error;
      return;
      end;
    if cur_val_level = int_val then scan_dimen(mu, false, true)
    else if level = mu_val then mu_error;
    end
  else begin back_input; scan_dimen(mu, false, false);
    if negative then negate(cur_val);
    end;
     $\langle$  Create a new glue specification whose width is cur_val; scan for its stretch and shrink components 488  $\rangle$ ;
  exit: end;
   $\langle$  Declare procedures needed for expressions 1779  $\rangle$ 
```

488. \langle Create a new glue specification whose width is *cur_val*; scan for its stretch and shrink components 488 $\rangle \equiv$

```
q  $\leftarrow$  new_spec(zero_glue); width(q)  $\leftarrow$  cur_val;
if scan_keyword("plus") then
  begin scan_dimen(mu, true, false); stretch(q)  $\leftarrow$  cur_val; stretch_order(q)  $\leftarrow$  cur_order;
  end;
if scan_keyword("minus") then
  begin scan_dimen(mu, true, false); shrink(q)  $\leftarrow$  cur_val; shrink_order(q)  $\leftarrow$  cur_order;
  end;
cur_val  $\leftarrow$  q
```

This code is used in section 487.

489. Here's a similar procedure that returns a pointer to a rule node. This routine is called just after \TeX has seen \hrule or \vrule ; therefore cur_cmd will be either $hrule$ or $vrule$. The idea is to store the default rule dimensions in the node, then to override them if 'height' or 'width' or 'depth' specifications are found (in any order).

```

define default_rule = 26214 { 0.4pt }
function scan_rule_spec: pointer;
  label reswitch;
  var q: pointer; { the rule node being created }
  begin q  $\leftarrow$  new_rule; { width, depth, and height all equal null_flag now }
  if cur_cmd = vrule then width(q)  $\leftarrow$  default_rule
  else begin height(q)  $\leftarrow$  default_rule; depth(q)  $\leftarrow$  0;
    end;
  reswitch: if scan_keyword("width") then
    begin scan_normal_dimen; width(q)  $\leftarrow$  cur_val; goto reswitch;
    end;
  if scan_keyword("height") then
    begin scan_normal_dimen; height(q)  $\leftarrow$  cur_val; goto reswitch;
    end;
  if scan_keyword("depth") then
    begin scan_normal_dimen; depth(q)  $\leftarrow$  cur_val; goto reswitch;
    end;
  scan_rule_spec  $\leftarrow$  q;
end;

```

490. Building token lists. The token lists for macros and for other things like `\mark` and `\output` and `\write` are produced by a procedure called *scan_toks*.

Before we get into the details of *scan_toks*, let's consider a much simpler task, that of converting the current string into a token list. The *str_toks* function does this; it classifies spaces as type *spacer* and everything else as type *other_char*.

The token list created by *str_toks* begins at *link(temp_head)* and ends at the value *p* that is returned. (If *p* = *temp_head*, the list is empty.)

⟨Declare ε -TeX procedures for token lists 1680⟩

```
function str_toks(b : pool_pointer): pointer; { converts str_pool[b .. pool_ptr - 1] to a token list }
  var p: pointer; { tail of the token list }
    q: pointer; { new node being added to the token list via store_new_token }
    t: halfword; { token being appended }
    k: pool_pointer; { index into str_pool }
  begin str_room(1); p ← temp_head; link(p) ← null; k ← b;
  while k < pool_ptr do
    begin t ← so(str_pool[k]);
    if t = "␣" then t ← space_token
    else t ← other_token + t;
    fast_store_new_token(t); incr(k);
    end;
  pool_ptr ← b; str_toks ← p;
end;
```

491. The main reason for wanting *str_toks* is the next function, *the_toks*, which has similar input/output characteristics.

This procedure is supposed to scan something like ‘`\skip\count12`’, i.e., whatever can follow ‘`\the`’, and it constructs a token list containing something like ‘`-3.0pt minus 0.5fill`’.

```
function the_toks: pointer;
  label exit;
  var old_setting: 0 .. max_selector; { holds selector setting }
    p, q, r: pointer; { used for copying a token list }
    b: pool_pointer; { base of temporary string }
    c: small_number; { value of cur_chr }
  begin ⟨Handle \unexpanded or \detokenize and return 1685⟩;
  get_x_token; scan_something_internal(tok_val, false);
  if cur_val_level ≥ ident_val then ⟨Copy the token list 492⟩
  else begin old_setting ← selector; selector ← new_string; b ← pool_ptr;
    case cur_val_level of
      int_val: print_int(cur_val);
      dimen_val: begin print_scaled(cur_val); print("pt");
        end;
      glue_val: begin print_spec(cur_val, "pt"); delete_glue_ref(cur_val);
        end;
      mu_val: begin print_spec(cur_val, "mu"); delete_glue_ref(cur_val);
        end;
    end; { there are no other cases }
    selector ← old_setting; the_toks ← str_toks(b);
  end;
exit: end;
```


492. \langle Copy the token list 492 $\rangle \equiv$

```

begin  $p \leftarrow temp\_head$ ;  $link(p) \leftarrow null$ ;
if  $cur\_val\_level = ident\_val$  then  $store\_new\_token(cs\_token\_flag + cur\_val)$ 
else if  $cur\_val \neq null$  then
  begin  $r \leftarrow link(cur\_val)$ ; { do not copy the reference count }
  while  $r \neq null$  do
    begin  $fast\_store\_new\_token(info(r))$ ;  $r \leftarrow link(r)$ ;
    end;
  end;
 $the\_toks \leftarrow p$ ;
end

```

This code is used in section 491.

493. Here's part of the *expand* subroutine that we are now ready to complete:

```

procedure  $ins\_the\_toks$ ;
  begin  $link(garbage) \leftarrow the\_toks$ ;  $ins\_list(link(temp\_head))$ ;
end;

```

494. The primitives `\number`, `\romannumeral`, `\string`, `\meaning`, `\fontname`, and `\jobname` are defined as follows.

ε -TeX adds `\eTeXrevision` such that `job_name_code` remains last.

pdfTeX adds `\pdftexrevision`, `\pdftexbanner`, `\pdffontname`, `\pdffontobjnum`, `\pdffontsize`, and `\pdfpageref` such that `job_name_code` remains last.

```

define number_code = 0 { command code for \number }
define roman_numeral_code = 1 { command code for \romannumeral }
define string_code = 2 { command code for \string }
define meaning_code = 3 { command code for \meaning }
define font_name_code = 4 { command code for \fontname }
define etex_convert_base = 5 { base for  $\varepsilon$ -TeX's command codes }
define eTeX_revision_code = etex_convert_base { command code for \eTeXrevision }
define etex_convert_codes = etex_convert_base + 1 { end of  $\varepsilon$ -TeX's command codes }
define expanded_code = etex_convert_codes { command code for \expanded }
define pdftex_first_expand_code = expanded_code + 1 { base for pdfTeX's command codes }
define pdftex_revision_code = pdftex_first_expand_code + 0 { command code for \pdftexrevision }
define pdftex_banner_code = pdftex_first_expand_code + 1 { command code for \pdftexbanner }
define pdf_font_name_code = pdftex_first_expand_code + 2 { command code for \pdffontname }
define pdf_font_objnum_code = pdftex_first_expand_code + 3 { command code for \pdffontobjnum }
define pdf_font_size_code = pdftex_first_expand_code + 4 { command code for \pdffontsize }
define pdf_page_ref_code = pdftex_first_expand_code + 5 { command code for \pdfpageref }
define pdf_xform_name_code = pdftex_first_expand_code + 6 { command code for \pdfxformname }
define pdf_escape_string_code = pdftex_first_expand_code + 7 { command code for \pdfescapestring }
define pdf_escape_name_code = pdftex_first_expand_code + 8 { command code for \pdfescapename }
define left_margin_kern_code = pdftex_first_expand_code + 9 { command code for \leftmarginkern }
define right_margin_kern_code = pdftex_first_expand_code + 10
    { command code for \rightmarginkern }
define pdf_strcmp_code = pdftex_first_expand_code + 11 { command code for \pdfstrcmp }
define pdf_colorstack_init_code = pdftex_first_expand_code + 12
    { command code for \pdfcolorstackinit }
define pdf_escape_hex_code = pdftex_first_expand_code + 13 { command code for \pdfescapehex }
define pdf_unescape_hex_code = pdftex_first_expand_code + 14 { command code for \pdfunescapehex }
define pdf_creation_date_code = pdftex_first_expand_code + 15 { command code for \pdfcreationdate }
define pdf_file_mod_date_code = pdftex_first_expand_code + 16 { command code for \pdffilemoddate }
define pdf_file_size_code = pdftex_first_expand_code + 17 { command code for \pdffilesize }
define pdf_md5five_sum_code = pdftex_first_expand_code + 18 { command code for \pdfmd5fivesum }
define pdf_file_dump_code = pdftex_first_expand_code + 19 { command code for \pdffiledump }
define pdf_match_code = pdftex_first_expand_code + 20 { command code for \pdfmatch }
define pdf_last_match_code = pdftex_first_expand_code + 21 { command code for \pdflastmatch }
define uniform_deviate_code = pdftex_first_expand_code + 22 { end of pdfTeX's command codes }
define normal_deviate_code = pdftex_first_expand_code + 23 { end of pdfTeX's command codes }
define pdf_insert_ht_code = pdftex_first_expand_code + 24 { command code for \pdfinsertht }
define pdf_ximage_bbox_code = pdftex_first_expand_code + 25 { command code for \pdfximagebbox }
define pdftex_convert_codes = pdftex_first_expand_code + 26 { end of pdfTeX's command codes }
define job_name_code = pdftex_convert_codes { command code for \jobname }

```

(Put each of TeX's primitives into the hash table 244) $\pm\equiv$

```

primitive("number", convert, number_code);
primitive("romannumeral", convert, roman_numeral_code);
primitive("string", convert, string_code);
primitive("meaning", convert, meaning_code);
primitive("fontname", convert, font_name_code);
primitive("expanded", convert, expanded_code);

```

```
primitive("pdftexrevision", convert, pdftex_revision_code);
primitive("pdftexbanner", convert, pdftex_banner_code);
primitive("pdffontname", convert, pdf_font_name_code);
primitive("pdffontobjnum", convert, pdf_font_objnum_code);
primitive("pdffontsize", convert, pdf_font_size_code);
primitive("pdfpageref", convert, pdf_page_ref_code);
primitive("leftmarginkern", convert, left_margin_kern_code);
primitive("rightmarginkern", convert, right_margin_kern_code);
primitive("pdfxformname", convert, pdf_xform_name_code);
primitive("pdfescapestring", convert, pdf_escape_string_code);
primitive("pdfescapeiname", convert, pdf_escape_name_code);
primitive("pdfescapehex", convert, pdf_escape_hex_code);
primitive("pdfunescapehex", convert, pdf_unescape_hex_code);
primitive("pdfcreationdate", convert, pdf_creation_date_code);
primitive("pdffilemoddate", convert, pdf_file_mod_date_code);
primitive("pdffilesize", convert, pdf_file_size_code);
primitive("pdfmdfivesum", convert, pdf_md5sum_code);
primitive("pdffiledump", convert, pdf_file_dump_code);
primitive("pdfmatch", convert, pdf_match_code);
primitive("pdflastmatch", convert, pdf_last_match_code);
primitive("pdfstrcmp", convert, pdf_strcmp_code);
primitive("pdfcolorstackinit", convert, pdf_colorstack_init_code);
primitive("pdfuniformdeviate", convert, uniform_deviate_code);
primitive("pdfnormaldeviate", convert, normal_deviate_code);

primitive("jobname", convert, job_name_code);
primitive("pdfinsertht", convert, pdf_insert_ht_code);
primitive("pdfximagebbox", convert, pdf_ximage_bbox_code);
```

495. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
convert: case chr_code of
  number_code: print_esc("number");
  roman_numeral_code: print_esc("romannumeral");
  string_code: print_esc("string");
  meaning_code: print_esc("meaning");
  font_name_code: print_esc("fontname");
  eTeX_revision_code: print_esc("eTeXrevision");
  expanded_code: print_esc("expanded");
  pdftex_revision_code: print_esc("pdftexrevision");
  pdftex_banner_code: print_esc("pdftexbanner");
  pdf_font_name_code: print_esc("pdffontname");
  pdf_font_objnum_code: print_esc("pdffontobjnum");
  pdf_font_size_code: print_esc("pdffontsize");
  pdf_page_ref_code: print_esc("pdfpageref");
  left_margin_kern_code: print_esc("leftmarginkern");
  right_margin_kern_code: print_esc("rightmarginkern");
  pdf_xform_name_code: print_esc("pdfxformname");
  pdf_escape_string_code: print_esc("pdfescapestring");
  pdf_escape_name_code: print_esc("pdfescapename");
  pdf_escape_hex_code: print_esc("pdfescapehex");
  pdf_unescape_hex_code: print_esc("pdfunescapehex");
  pdf_creation_date_code: print_esc("pdfcreationdate");
  pdf_file_mod_date_code: print_esc("pdffilemoddate");
  pdf_file_size_code: print_esc("pdffilesize");
  pdf_md5_sum_code: print_esc("pdfmd5sum");
  pdf_file_dump_code: print_esc("pdffiledump");
  pdf_match_code: print_esc("pdfmatch");
  pdf_last_match_code: print_esc("pdflastmatch");
  pdf_strcmp_code: print_esc("pdfstrcmp");
  pdf_colorstack_init_code: print_esc("pdfcolorstackinit");
  uniform_deviate_code: print_esc("pdfuniformdeviate");
  normal_deviate_code: print_esc("pdfnormaldeviate");
  pdf_insert_ht_code: print_esc("pdfinsertht");
  pdf_ximage_bbox_code: print_esc("pdfximagebbox");
othercases print_esc("jobname")
endcases;
```

496. The procedure *conv_toks* uses *str_toks* to insert the token list for *convert* functions into the scanner; ‘\outer’ control sequences are allowed to follow ‘\string’ and ‘\meaning’.

The extra temp string *u* is needed because *pdf_scan_ext_toks* incorporates any pending string in its output. In order to save such a pending string, we have to create a temporary string that is destroyed immediately after.

```

define save_cur_string ≡
    if str_start[str_ptr] < pool_ptr then u ← make_string
define restore_cur_string ≡
    if u ≠ 0 then
        begin decr(str_ptr); u ← 0;
        end

procedure conv_toks;
    label exit;
    var old_setting: 0 .. max_selector; { holds selector setting }
        p, q: pointer; c: number_code .. job_name_code; { desired type of conversion }
        save_scanner_status: small_number; { scanner_status upon entry }
        save_def_ref: pointer; { def_ref upon entry, important if inside ‘\message’ }
        save_warning_index: pointer; bool: boolean; { temp boolean }
        i: integer; { first temp integer }
        j: integer; { second temp integer }
        b: pool_pointer; { base of temporary string }
        s: str_number; { first temp string }
        t: str_number; { second temp string }
        u: str_number; { saved current string string }
    begin c ← cur_chr; u ← 0; { will become non-nil if a string is already being built }
    ⟨ Scan the argument for command c 497 ⟩;
    old_setting ← selector; selector ← new_string; b ← pool_ptr; ⟨ Print the result of command c 498 ⟩;
    selector ← old_setting; link(garbage) ← str_toks(b); ins_list(link(temp_head));
    exit: end;

```

497. \langle Scan the argument for command *c* 497 $\rangle \equiv$

```

case c of
  number_code, roman_numeral_code: scan_int;
  string_code, meaning_code: begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  normal;
    get_token; scanner_status  $\leftarrow$  save_scanner_status;
  end;
  font_name_code: scan_font_ident;
  eTeX_revision_code: do_nothing;
  expanded_code: begin save_scanner_status  $\leftarrow$  scanner_status; save_warning_index  $\leftarrow$  warning_index;
    save_def_ref  $\leftarrow$  def_ref; save_cur_string; scan_pdf_ext_toks; warning_index  $\leftarrow$  save_warning_index;
    scanner_status  $\leftarrow$  save_scanner_status; ins_list(link(def_ref)); free_avail(def_ref);
    def_ref  $\leftarrow$  save_def_ref; restore_cur_string; return;
  end;
  pdftex_revision_code: do_nothing;
  pdftex_banner_code: do_nothing;
  pdf_font_name_code, pdf_font_objnum_code, pdf_font_size_code: begin scan_font_ident;
    if cur_val = null_font then pdf_error("font", "invalid_font_identifier");
    if c  $\neq$  pdf_font_size_code then
      begin pdf_check_vf_cur_val;
        if  $\neg$ font_used[cur_val] then pdf_init_font_cur_val;
      end;
    end;
  pdf_page_ref_code: begin scan_int;
    if cur_val  $\leq$  0 then pdf_error("pageref", "invalid_page_number");
  end;
  left_margin_kern_code, right_margin_kern_code: begin scan_register_num; fetch_box(p);
    if (p = null)  $\vee$  (type(p)  $\neq$  hlist_node) then pdf_error("marginkern", "a_non-empty_hbox_expected")
  end;
  pdf_xform_name_code: begin scan_int; pdf_check_obj(obj_type_xform, cur_val);
  end;
  pdf_escape_string_code: begin save_scanner_status  $\leftarrow$  scanner_status;
    save_warning_index  $\leftarrow$  warning_index; save_def_ref  $\leftarrow$  def_ref; save_cur_string; scan_pdf_ext_toks;
    s  $\leftarrow$  tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref  $\leftarrow$  save_def_ref;
    warning_index  $\leftarrow$  save_warning_index; scanner_status  $\leftarrow$  save_scanner_status; b  $\leftarrow$  pool_ptr;
    escapestring(str_start[s]); link(garbage)  $\leftarrow$  str_toks(b); flush_str(s); ins_list(link(temp_head));
    restore_cur_string; return;
  end;
  pdf_escape_name_code: begin save_scanner_status  $\leftarrow$  scanner_status;
    save_warning_index  $\leftarrow$  warning_index; save_def_ref  $\leftarrow$  def_ref; save_cur_string; scan_pdf_ext_toks;
    s  $\leftarrow$  tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref  $\leftarrow$  save_def_ref;
    warning_index  $\leftarrow$  save_warning_index; scanner_status  $\leftarrow$  save_scanner_status; b  $\leftarrow$  pool_ptr;
    escapename(str_start[s]); link(garbage)  $\leftarrow$  str_toks(b); flush_str(s); ins_list(link(temp_head));
    restore_cur_string; return;
  end;
  pdf_escape_hex_code: begin save_scanner_status  $\leftarrow$  scanner_status; save_warning_index  $\leftarrow$  warning_index;
    save_def_ref  $\leftarrow$  def_ref; save_cur_string; scan_pdf_ext_toks; s  $\leftarrow$  tokens_to_string(def_ref);
    delete_token_ref(def_ref); def_ref  $\leftarrow$  save_def_ref; warning_index  $\leftarrow$  save_warning_index;
    scanner_status  $\leftarrow$  save_scanner_status; b  $\leftarrow$  pool_ptr; escapehex(str_start[s]);
    link(garbage)  $\leftarrow$  str_toks(b); flush_str(s); ins_list(link(temp_head)); restore_cur_string; return;
  end;
  pdf_unescape_hex_code: begin save_scanner_status  $\leftarrow$  scanner_status;
    save_warning_index  $\leftarrow$  warning_index; save_def_ref  $\leftarrow$  def_ref; save_cur_string; scan_pdf_ext_toks;

```

```

s ← tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref ← save_def_ref;
warning_index ← save_warning_index; scanner_status ← save_scanner_status; b ← pool_ptr;
unescapehex(str_start[s]); link(garbage) ← str_toks(b); flush_str(s); ins_list(link(temp_head));
restore_cur_string; return;
end;

pdf_creation_date_code: begin b ← pool_ptr; getcreationdate; link(garbage) ← str_toks(b);
ins_list(link(temp_head)); return;
end;

pdf_file_mod_date_code: begin save_scanner_status ← scanner_status;
save_warning_index ← warning_index; save_def_ref ← def_ref; save_cur_string; scan_pdf_ext_toks;
s ← tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref ← save_def_ref;
warning_index ← save_warning_index; scanner_status ← save_scanner_status; b ← pool_ptr;
getfilemoddate(s); link(garbage) ← str_toks(b); flush_str(s); ins_list(link(temp_head));
restore_cur_string; return;
end;

pdf_file_size_code: begin save_scanner_status ← scanner_status; save_warning_index ← warning_index;
save_def_ref ← def_ref; save_cur_string; scan_pdf_ext_toks; s ← tokens_to_string(def_ref);
delete_token_ref(def_ref); def_ref ← save_def_ref; warning_index ← save_warning_index;
scanner_status ← save_scanner_status; b ← pool_ptr; getfilesize(s); link(garbage) ← str_toks(b);
flush_str(s); ins_list(link(temp_head)); restore_cur_string; return;
end;

pdf_md5sum_code: begin save_scanner_status ← scanner_status;
save_warning_index ← warning_index; save_def_ref ← def_ref; save_cur_string;
bool ← scan_keyword("file"); scan_pdf_ext_toks; s ← tokens_to_string(def_ref);
delete_token_ref(def_ref); def_ref ← save_def_ref; warning_index ← save_warning_index;
scanner_status ← save_scanner_status; b ← pool_ptr; getmd5sum(s, bool); link(garbage) ← str_toks(b);
flush_str(s); ins_list(link(temp_head)); restore_cur_string; return;
end;

pdf_file_dump_code: begin save_scanner_status ← scanner_status; save_warning_index ← warning_index;
save_def_ref ← def_ref; save_cur_string; { scan offset }
cur_val ← 0;
if (scan_keyword("offset")) then
  begin scan_int;
  if (cur_val < 0) then
    begin print_err("Bad_file_offset");
    help2("A_file_offset_must_be_between_0_and_2^{31}-1,")
    ("I_changed_this_one_to_zero."); int_error(cur_val); cur_val ← 0;
    end;
  end;
end;

i ← cur_val; { scan length }
cur_val ← 0;
if (scan_keyword("length")) then
  begin scan_int;
  if (cur_val < 0) then
    begin print_err("Bad_dump_length");
    help2("A_dump_length_must_be_between_0_and_2^{31}-1,")
    ("I_changed_this_one_to_zero."); int_error(cur_val); cur_val ← 0;
    end;
  end;
end;

j ← cur_val; { scan file name }
scan_pdf_ext_toks; s ← tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref ← save_def_ref;
warning_index ← save_warning_index; scanner_status ← save_scanner_status; b ← pool_ptr;

```

```

getfiledump(s,i,j); link(garbage) ← str_toks(b); flush_str(s); ins_list(link(temp_head));
restore_cur_string; return;
end;
pdf_match_code: begin save_scanner_status ← scanner_status; save_warning_index ← warning_index;
save_def_ref ← def_ref; save_cur_string; { scan for icase }
bool ← scan_keyword("icase"); { scan for subcount }
i ← -1; { default for subcount }
if scan_keyword("subcount") then
  begin scan_int; i ← cur_val;
  end;
scan_pdf_ext_toks; s ← tokens_to_string(def_ref); delete_token_ref(def_ref); scan_pdf_ext_toks;
t ← tokens_to_string(def_ref); delete_token_ref(def_ref); def_ref ← save_def_ref;
warning_index ← save_warning_index; scanner_status ← save_scanner_status; b ← pool_ptr;
matchstrings(s,t,i,bool); link(garbage) ← str_toks(b); flush_str(t); flush_str(s);
ins_list(link(temp_head)); restore_cur_string; return;
end;
pdf_last_match_code: begin scan_int;
if cur_val < 0 then
  begin print_err("Bad_match_number");
  help2("Since I expected zero or a positive number,")
  ("I changed this one to zero."); int_error(cur_val); cur_val ← 0;
  end;
b ← pool_ptr; getmatch(cur_val); link(garbage) ← str_toks(b); ins_list(link(temp_head)); return;
end;
pdf_strcmp_code: begin save_scanner_status ← scanner_status; save_warning_index ← warning_index;
save_def_ref ← def_ref; save_cur_string; compare_strings; def_ref ← save_def_ref;
warning_index ← save_warning_index; scanner_status ← save_scanner_status; restore_cur_string;
end;
pdf_colorstack_init_code: begin bool ← scan_keyword("page");
if scan_keyword("direct") then cur_val ← direct_always
else if scan_keyword("page") then cur_val ← direct_page
  else cur_val ← set_origin;
save_scanner_status ← scanner_status; save_warning_index ← warning_index; save_def_ref ← def_ref;
save_cur_string; scan_pdf_ext_toks; s ← tokens_to_string(def_ref); delete_token_ref(def_ref);
def_ref ← save_def_ref; warning_index ← save_warning_index; scanner_status ← save_scanner_status;
cur_val ← newcolorstack(s, cur_val, bool); flush_str(s); cur_val_level ← int_val;
if cur_val < 0 then
  begin print_err("Too_many_color_stacks");
  help2("The number of color stacks is limited to 32768.")
  ("I'll use the default color stack 0 here."); error; cur_val ← 0; restore_cur_string;
  end;
end;
job_name_code: if job_name = 0 then open_log_file;
uniform_deviate_code: scan_int;
normal_deviate_code: do_nothing;
pdf_insert_ht_code: scan_register_num;
pdf_ximage_bbox_code: begin scan_int; pdf_check_obj(obj_type_ximage, cur_val);
i ← obj_ximage_data(cur_val); scan_int; j ← cur_val;
if (j < 1) ∨ (j > 4) then pdf_error("pdfximagebbox","invalid_parameter");
end;
end { there are no other cases }

```

This code is used in section 496.

498. \langle Print the result of command *c* 498 $\rangle \equiv$

```

case c of
  number_code: print_int(cur_val);
  roman_numerals_code: print_roman_int(cur_val);
  string_code: if cur_cs  $\neq$  0 then sprint_cs(cur_cs)
    else print_char(cur_chr);
  meaning_code: print_meaning;
  font_name_code: begin print(font_name[cur_val]);
    if font_size[cur_val]  $\neq$  font_dsize[cur_val] then
      begin print("\_at\_"); print_scaled(font_size[cur_val]); print("pt");
      end;
    end;
  eTeX_revision_code: print(eTeX_revision);
  pdftex_revision_code: print(pdftex_revision);
  pdftex_banner_code: print(pdftex_banner);
  pdf_font_name_code, pdf_font_objnum_code: begin set_ff(cur_val);
    if c = pdf_font_name_code then print_int(obj_info(pdf_font_num[ff]));
    else print_int(pdf_font_num[ff]);
    end;
  pdf_font_size_code: begin print_scaled(font_size[cur_val]); print("pt");
    end;
  pdf_page_ref_code: print_int(get_obj(obj_type_page, cur_val, false));
  left_margin_kern_code: begin p  $\leftarrow$  list_ptr(p);
    while (p  $\neq$  null)  $\wedge$  (cp_skipable(p)  $\vee$  (( $\neg$ is_char_node(p))  $\wedge$  (type(p) = glue_node)  $\wedge$  (subtype(p) =
      left_skip_code + 1))) do p  $\leftarrow$  link(p);
    if (p  $\neq$  null)  $\wedge$  ( $\neg$ is_char_node(p))  $\wedge$  (type(p) = margin_kern_node)  $\wedge$  (subtype(p) = left_side) then
      print_scaled(width(p))
    else print("0");
    print("pt");
    end;
  right_margin_kern_code: begin q  $\leftarrow$  list_ptr(p); p  $\leftarrow$  prev_rightmost(q, null);
    while (p  $\neq$  null)  $\wedge$  (cp_skipable(p)  $\vee$  (( $\neg$ is_char_node(p))  $\wedge$  (type(p) = glue_node)  $\wedge$  (subtype(p) =
      right_skip_code + 1))) do p  $\leftarrow$  prev_rightmost(q, p);
    if (p  $\neq$  null)  $\wedge$  ( $\neg$ is_char_node(p))  $\wedge$  (type(p) = margin_kern_node)  $\wedge$  (subtype(p) = right_side) then
      print_scaled(width(p))
    else print("0");
    print("pt");
    end;
  pdf_xform_name_code: print_int(obj_info(cur_val));
  pdf_strcmp_code: print_int(cur_val);
  pdf_colorstack_init_code: print_int(cur_val);
  uniform_deviate_code: print_int(unif_rand(cur_val));
  normal_deviate_code: print_int(norm_rand);
  pdf_insert_ht_code: begin i  $\leftarrow$  qi(cur_val); p  $\leftarrow$  page_ins_head;
    while i  $\geq$  subtype(link(p)) do p  $\leftarrow$  link(p);
    if subtype(p) = i then print_scaled(height(p))
    else print("0");
    print("pt");
    end;
  pdf_ximage_bbox_code: begin if is_pdf_image(i) then
    begin case j of
      1: print_scaled(epdf_orig_x(i));

```

```

2: print_scaled(epdf_orig_y(i));
3: print_scaled(epdf_orig_x(i) + image_width(i));
4: print_scaled(epdf_orig_y(i) + image_height(i));
endcases;
end
else print_scaled(0);
print("pt");
end;
job_name_code: print(job_name);
end { there are no other cases }

```

This code is used in section 496.

499. Now we can't postpone the difficulties any longer; we must bravely tackle *scan_toks*. This function returns a pointer to the tail of a new token list, and it also makes *def_ref* point to the reference count at the head of that list.

There are two boolean parameters, *macro_def* and *xpand*. If *macro_def* is true, the goal is to create the token list for a macro definition; otherwise the goal is to create the token list for some other TeX primitive: `\mark`, `\output`, `\everypar`, `\lowercase`, `\uppercase`, `\message`, `\errmessage`, `\write`, or `\special`. In the latter cases a left brace must be scanned next; this left brace will not be part of the token list, nor will the matching right brace that comes at the end. If *xpand* is false, the token list will simply be copied from the input using *get_token*. Otherwise all expandable tokens will be expanded until unexpandable tokens are left, except that the results of expanding '`\the`' are not expanded further. If both *macro_def* and *xpand* are true, the expansion applies only to the macro body (i.e., to the material following the first *left_brace* character).

The value of *cur_cs* when *scan_toks* begins should be the *eqtb* address of the control sequence to display in "runaway" error messages.

```

function scan_toks(macro_def, xpand : boolean): pointer;
  label found, continue, done, done1, done2;
  var t: halfword; { token representing the highest parameter number }
      s: halfword; { saved token }
      p: pointer; { tail of the token list being built }
      q: pointer; { new node being added to the token list via store_new_token }
      unbalance: halfword; { number of unmatched left braces }
      hash_brace: halfword; { possible '#{ } token }
  begin if macro_def then scanner_status ← defining else scanner_status ← absorbing;
  warning_index ← cur_cs; def_ref ← get_avail; token_ref_count(def_ref) ← null; p ← def_ref;
  hash_brace ← 0; t ← zero_token;
  if macro_def then ⟨Scan and build the parameter part of the macro definition 500⟩
  else scan_left_brace; { remove the compulsory left brace }
  ⟨Scan and build the body of the token list; goto found when finished 503⟩;
found: scanner_status ← normal;
if hash_brace ≠ 0 then store_new_token(hash_brace);
scan_toks ← p;
end;

```

500. \langle Scan and build the parameter part of the macro definition 500 $\rangle \equiv$

```

begin loop
  begin continue: get_token; { set cur_cmd, cur_chr, cur_tok }
  if cur_tok < right_brace_limit then goto done1;
  if cur_cmd = mac_param then  $\langle$  If the next character is a parameter number, make cur_tok a match
    token; but if it is a left brace, store 'left_brace', set hash_brace, and goto done 502  $\rangle$ ;
    store_new_token(cur_tok);
  end;
done1: store_new_token(end_match_token);
  if cur_cmd = right_brace then  $\langle$  Express shock at the missing left brace; goto found 501  $\rangle$ ;
done: end

```

This code is used in section 499.

501. \langle Express shock at the missing left brace; **goto** *found* 501 $\rangle \equiv$

```

begin print_err("Missing_{_}inserted"); incr(align_state);
help2("Where_was_the_left_brace?_You_said_something_like_`\def\{a}`",)
("which_I'm_going_to_interpret_as_`\def\{a}`."); error; goto found;
end

```

This code is used in section 500.

502. \langle If the next character is a parameter number, make *cur_tok* a *match* token; but if it is a left brace, store '*left_brace*', set *hash_brace*, and **goto** *done* 502 $\rangle \equiv$

```

begin s  $\leftarrow$  match_token + cur_chr; get_token;
if cur_tok < left_brace_limit then
  begin hash_brace  $\leftarrow$  cur_tok; store_new_token(cur_tok); store_new_token(end_match_token);
  goto done;
  end;
if t = zero_token + 9 then
  begin print_err("You_already_have_nine_parameters");
  help2("I'm_going_to_ignore_the_#_sign_you_just_used,",)
  ("as_well_as_the_token_that_followed_it."); error; goto continue;
  end
else begin incr(t);
  if cur_tok  $\neq$  t then
    begin print_err("Parameters_must_be_numbered_consecutively");
    help2("I've_inserted_the_digit_you_should_have_used_after_the_#.")
    ("Type_`1'_to_delete_what_you_did_use."); back_error;
    end;
    cur_tok  $\leftarrow$  s;
  end;
end

```

This code is used in section 500.

503. \langle Scan and build the body of the token list; **goto** *found* when finished **503** $\rangle \equiv$

```

unbalance  $\leftarrow$  1;
loop begin if xpand then  $\langle$  Expand the next part of the input 504  $\rangle$ 
  else get_token;
  if cur_tok  $<$  right_brace_limit then
    if cur_cmd  $<$  right_brace then incr(unbalance)
    else begin decr(unbalance);
      if unbalance = 0 then goto found;
    end
  else if cur_cmd = mac_param then
    if macro_def then  $\langle$  Look for parameter number or ## 505  $\rangle$ ;
    store_new_token(cur_tok);
  end

```

This code is used in section 499.

504. Here we insert an entire token list created by *the_toks* without expanding it further.

\langle Expand the next part of the input **504** $\rangle \equiv$

```

begin loop
  begin get_next;
  if cur_cmd  $\geq$  call then
    if info(link(cur_chr)) = protected_token then
      begin cur_cmd  $\leftarrow$  relax; cur_chr  $\leftarrow$  no_expand_flag;
    end;
  if cur_cmd  $\leq$  max_command then goto done2;
  if cur_cmd  $\neq$  the then expand
  else begin q  $\leftarrow$  the_toks;
    if link(temp_head)  $\neq$  null then
      begin link(p)  $\leftarrow$  link(temp_head); p  $\leftarrow$  q;
    end;
  end;
end;
done2: x_token
end

```

This code is used in section 503.

505. \langle Look for parameter number or ## **505** $\rangle \equiv$

```

begin s  $\leftarrow$  cur_tok;
if xpand then get_x_token
else get_token;
if cur_cmd  $\neq$  mac_param then
  if (cur_tok  $\leq$  zero_token)  $\vee$  (cur_tok  $>$  t) then
    begin print_err("Illegal_parameter_number_in_definition_of_"); sprint_cs(warning_index);
    help3("You_meant_to_type_##_instead_of_#,_right?")
    ("Or_maybe_a_}was_forgotten_somewhere_earlier,_and_things")
    ("are_all_screwed_up?_I'm_going_to_assume_that_you_meant_##."); back_error; cur_tok  $\leftarrow$  s;
    end
  else cur_tok  $\leftarrow$  out_param_token - "0" + cur_chr;
end

```

This code is used in section 503.

506. Another way to create a token list is via the `\read` command. The sixteen files potentially usable for reading appear in the following global variables. The value of `read_open[n]` will be *closed* if stream number *n* has not been opened or if it has been fully read; *just_open* if an `\openin` but not a `\read` has been done; and *normal* if it is open and ready to read the next line.

```

define closed = 2 { not open, or at end of file }
define just_open = 1 { newly opened, first line not yet read }
⟨Global variables 13⟩ +=
read_file: array [0 .. 15] of alpha_file; { used for \read }
read_open: array [0 .. 16] of normal .. closed; { state of read_file[n] }

```

507. ⟨Set initial values of key variables 21⟩ +=
for *k* ← 0 **to** 16 **do** *read_open*[*k*] ← *closed*;

508. The *read_toks* procedure constructs a token list like that for any macro definition, and makes *cur_val* point to it. Parameter *r* points to the control sequence that will receive this token list.

```

procedure read_toks(n : integer; r : pointer; j : halfword);
  label done;
  var p: pointer; { tail of the token list }
      q: pointer; { new node being added to the token list via store_new_token }
      s: integer; { saved value of align_state }
      m: small_number; { stream number }
  begin scanner_status ← defining; warning_index ← r; def_ref ← get_avail;
  token_ref_count(def_ref) ← null; p ← def_ref; { the reference count }
  store_new_token(end_match_token);
  if (n < 0) ∨ (n > 15) then m ← 16 else m ← n;
  s ← align_state; align_state ← 1000000; { disable tab marks, etc. }
  repeat ⟨Input and store tokens from the next line of the file 509⟩;
  until align_state = 1000000;
  cur_val ← def_ref; scanner_status ← normal; align_state ← s;
  end;

```

509. \langle Input and store tokens from the next line of the file 509 $\rangle \equiv$

```

begin_file_reading; name  $\leftarrow m + 1$ ;
if read_open[m] = closed then  $\langle$ Input for \read from the terminal 510 $\rangle$ 
else if read_open[m] = just_open then  $\langle$ Input the first line of read_file[m] 511 $\rangle$ 
    else  $\langle$ Input the next line of read_file[m] 512 $\rangle$ ;
limit  $\leftarrow$  last;
if end_line_char_inactive then decr(limit)
else buffer[limit]  $\leftarrow$  end_line_char;
first  $\leftarrow$  limit + 1; loc  $\leftarrow$  start; state  $\leftarrow$  new_line;
 $\langle$ Handle \readline and goto done 1758 $\rangle$ ;
loop begin get_token;
    if cur_tok = 0 then goto done; { cur_cmd = cur_chr = 0 will occur at the end of the line }
    if align_state < 1000000 then { unmatched '}' aborts the line }
        begin repeat get_token;
            until cur_tok = 0;
            align_state  $\leftarrow$  1000000; goto done;
        end;
    store_new_token(cur_tok);
end;
done: end_file_reading

```

This code is used in section 508.

510. Here we input on-line into the *buffer* array, prompting the user explicitly if $n \geq 0$. The value of n is set negative so that additional prompts will not be given in the case of multi-line input.

\langle Input for \read from the terminal 510 $\rangle \equiv$

```

if interaction > nonstop_mode then
    if n < 0 then prompt_input("")
    else begin wake_up_terminal; print_ln; sprint_cs(r); prompt_input("="); n  $\leftarrow$  -1;
        end
    else fatal_error("***_(cannot_\read_from_terminal_in_nonstop_modes)")

```

This code is used in section 509.

511. The first line of a file must be treated specially, since *input_ln* must be told not to start with *get*.

\langle Input the first line of read_file[m] 511 $\rangle \equiv$

```

if input_ln(read_file[m], false) then read_open[m]  $\leftarrow$  normal
else begin a_close(read_file[m]); read_open[m]  $\leftarrow$  closed;
    end

```

This code is used in section 509.

512. An empty line is appended at the end of a *read_file*.

\langle Input the next line of read_file[m] 512 $\rangle \equiv$

```

begin if  $\neg$ input_ln(read_file[m], true) then
    begin a_close(read_file[m]); read_open[m]  $\leftarrow$  closed;
    if align_state  $\neq$  1000000 then
        begin runaway; print_err("File_ended_within_"); print_esc("read");
        help1("This_\read_has_unbalanced_braces."); align_state  $\leftarrow$  1000000; limit  $\leftarrow$  0; error;
        end;
    end;
end

```

This code is used in section 509.

513. Conditional processing. We consider now the way TeX handles various kinds of `\if` commands.

```

define unless_code = 32 { amount added for ‘\unless’ prefix }
define if_char_code = 0 { ‘\if’ }
define if_cat_code = 1 { ‘\ifcat’ }
define if_int_code = 2 { ‘\ifnum’ }
define if_dim_code = 3 { ‘\ifdim’ }
define if_odd_code = 4 { ‘\ifodd’ }
define if_vmode_code = 5 { ‘\ifvmode’ }
define if_hmode_code = 6 { ‘\ifhmode’ }
define if_mmode_code = 7 { ‘\ifmmode’ }
define if_inner_code = 8 { ‘\ifinner’ }
define if_void_code = 9 { ‘\ifvoid’ }
define if_hbox_code = 10 { ‘\ifhbox’ }
define if_vbox_code = 11 { ‘\ifvbox’ }
define if_x_code = 12 { ‘\ifx’ }
define if_eof_code = 13 { ‘\ifeof’ }
define if_true_code = 14 { ‘\iftrue’ }
define if_false_code = 15 { ‘\iffalse’ }
define if_case_code = 16 { ‘\ifcase’ }
define if_pdfprimitive_code = 21 { ‘\ifpdfprimitive’ }

```

⟨ Put each of TeX’s primitives into the hash table 244 ⟩ +=

```

primitive("if", if_test, if_char_code); primitive("ifcat", if_test, if_cat_code);
primitive("ifnum", if_test, if_int_code); primitive("ifdim", if_test, if_dim_code);
primitive("ifodd", if_test, if_odd_code); primitive("ifvmode", if_test, if_vmode_code);
primitive("ifhmode", if_test, if_hmode_code); primitive("ifmmode", if_test, if_mmode_code);
primitive("ifinner", if_test, if_inner_code); primitive("ifvoid", if_test, if_void_code);
primitive("ifhbox", if_test, if_hbox_code); primitive("ifvbox", if_test, if_vbox_code);
primitive("ifx", if_test, if_x_code); primitive("ifeof", if_test, if_eof_code);
primitive("iftrue", if_test, if_true_code); primitive("iffalse", if_test, if_false_code);
primitive("ifcase", if_test, if_case_code); primitive("ifpdfprimitive", if_test, if_pdfprimitive_code);

```

514. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

if_test: **begin if** *chr_code* \geq *unless_code* **then** *print_esc*("unless");

case *chr_code mod unless_code* **of**

if_cat_code: *print_esc*("ifcat");

if_int_code: *print_esc*("ifnum");

if_dim_code: *print_esc*("ifdim");

if_odd_code: *print_esc*("ifodd");

if_vmode_code: *print_esc*("ifvmode");

if_hmode_code: *print_esc*("ifhmode");

if_mmode_code: *print_esc*("ifmmode");

if_inner_code: *print_esc*("ifinner");

if_void_code: *print_esc*("ifvoid");

if_hbox_code: *print_esc*("ifhbox");

if_vbox_code: *print_esc*("ifvbox");

if_x_code: *print_esc*("ifx");

if_eof_code: *print_esc*("ifeof");

if_true_code: *print_esc*("iftrue");

if_false_code: *print_esc*("iffalse");

if_case_code: *print_esc*("ifcase");

if_pdfprimitive_code: *print_esc*("ifpdfprimitive");

\langle Cases of *if_test* for *print_cmd_chr* 1761 \rangle

othercases *print_esc*("if")

endcases;

end;

515. Conditions can be inside conditions, and this nesting has a stack that is independent of the *save_stack*.

Four global variables represent the top of the condition stack: *cond_ptr* points to pushed-down entries, if any; *if_limit* specifies the largest code of a *fi_or_else* command that is syntactically legal; *cur_if* is the name of the current type of conditional; and *if_line* is the line number at which it began.

If no conditions are currently in progress, the condition stack has the special state *cond_ptr* = *null*, *if_limit* = *normal*, *cur_if* = 0, *if_line* = 0. Otherwise *cond_ptr* points to a two-word node; the *type*, *subtype*, and *link* fields of the first word contain *if_limit*, *cur_if*, and *cond_ptr* at the next level, and the second word contains the corresponding *if_line*.

define *if_node_size* = 2 { number of words in stack entry for conditionals }

define *if_line_field*(#) \equiv *mem*[# + 1].*int*

define *if_code* = 1 { code for \if... being evaluated }

define *fi_code* = 2 { code for \fi }

define *else_code* = 3 { code for \else }

define *or_code* = 4 { code for \or }

\langle Global variables 13 $\rangle + \equiv$

cond_ptr: *pointer*; { top of the condition stack }

if_limit: *normal* .. *or_code*; { upper bound on *fi_or_else* codes }

cur_if: *small_number*; { type of conditional being worked on }

if_line: *integer*; { line where that conditional began }

516. \langle Set initial values of key variables 21 $\rangle + \equiv$

cond_ptr \leftarrow *null*; *if_limit* \leftarrow *normal*; *cur_if* \leftarrow 0; *if_line* \leftarrow 0;

517. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

primitive("fi", *fi_or_else*, *fi_code*); *text*(*frozen_fi*) \leftarrow "fi"; *eqtb*[*frozen_fi*] \leftarrow *eqtb*[*cur_val*];

primitive("or", *fi_or_else*, *or_code*); *primitive*("else", *fi_or_else*, *else_code*);

518. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
fi_or_else: **if** *chr_code* = *fi_code* **then** *print_esc*("fi")
 else if *chr_code* = *or_code* **then** *print_esc*("or")
 else *print_esc*("else");

519. When we skip conditional text, we keep track of the line number where skipping began, for use in error messages.

\langle Global variables 13 $\rangle + \equiv$
skip_line: *integer*; { skipping began here }

520. Here is a procedure that ignores text until coming to an `\or`, `\else`, or `\fi` at the current level of `\if... \fi` nesting. After it has acted, *cur_chr* will indicate the token that was found, but *cur_tok* will not be set (because this makes the procedure run faster).

```
procedure pass_text;
  label done;
  var l: integer; { level of \if... \fi nesting }
      save_scanner_status: small_number; { scanner_status upon entry }
  begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  skipping; l  $\leftarrow$  0; skip_line  $\leftarrow$  line;
  loop begin get_next;
    if cur_cmd = fi_or_else then
      begin if l = 0 then goto done;
      if cur_chr = fi_code then decr(l);
      end
    else if cur_cmd = if_test then incr(l);
    end;
  done: scanner_status  $\leftarrow$  save_scanner_status;
  if tracing_ifs > 0 then show_cur_cmd_chr;
  end;
```

521. When we begin to process a new `\if`, we set *if_limit* \leftarrow *if_code*; then if `\or` or `\else` or `\fi` occurs before the current `\if` condition has been evaluated, `\relax` will be inserted. For example, a sequence of commands like `'\ifvoid1\else...\fi'` would otherwise require something after the '1'.

\langle Push the condition stack 521 $\rangle \equiv$
begin *p* \leftarrow *get_node*(*if_node_size*); *link*(*p*) \leftarrow *cond_ptr*; *type*(*p*) \leftarrow *if_limit*; *subtype*(*p*) \leftarrow *cur_if*;
 if_line_field(*p*) \leftarrow *if_line*; *cond_ptr* \leftarrow *p*; *cur_if* \leftarrow *cur_chr*; *if_limit* \leftarrow *if_code*; *if_line* \leftarrow *line*;
end

This code is used in section 524.

522. \langle Pop the condition stack 522 $\rangle \equiv$
begin if *if_stack*[*in_open*] = *cond_ptr* **then** *if_warning*;
 { conditionals possibly not properly nested with files }
 p \leftarrow *cond_ptr*; *if_line* \leftarrow *if_line_field*(*p*); *cur_if* \leftarrow *subtype*(*p*); *if_limit* \leftarrow *type*(*p*); *cond_ptr* \leftarrow *link*(*p*);
 free_node(*p*, *if_node_size*);
end

This code is used in sections 524, 526, 535, and 536.

523. Here's a procedure that changes the *if_limit* code corresponding to a given value of *cond_ptr*.

```

procedure change_if_limit(l : small_number; p : pointer);
  label exit;
  var q : pointer;
  begin if p = cond_ptr then if_limit  $\leftarrow$  l { that's the easy case }
  else begin q  $\leftarrow$  cond_ptr;
    loop begin if q = null then confusion("if");
      if link(q) = p then
        begin type(q)  $\leftarrow$  l; return;
      end;
      q  $\leftarrow$  link(q);
    end;
  end;
exit : end;

```

524. A condition is started when the *expand* procedure encounters an *if_test* command; in that case *expand* reduces to *conditional*, which is a recursive procedure.

```

procedure conditional;
  label exit, common_ending;
  var b : boolean; { is the condition true? }
  e : boolean; { keep track of nested csnames }
  r : "<" .. ">"; { relation to be evaluated }
  m, n : integer; { to be tested against the second operand }
  p, q : pointer; { for traversing token lists in \ifx tests }
  save_scanner_status : small_number; { scanner_status upon entry }
  save_cond_ptr : pointer; { cond_ptr corresponding to this conditional }
  this_if : small_number; { type of this conditional }
  is_unless : boolean; { was this if preceded by '\unless' ? }
  begin if tracing_ifs > 0 then
    if tracing_commands  $\leq$  1 then show_cur_cmd_chr;
    < Push the condition stack 521 >; save_cond_ptr  $\leftarrow$  cond_ptr; is_unless  $\leftarrow$  (cur_chr  $\geq$  unless_code);
    this_if  $\leftarrow$  cur_chr mod unless_code;
    < Either process \ifcase or set b to the value of a boolean condition 527 >;
    if is_unless then b  $\leftarrow$   $\neg b$ ;
    if tracing_commands > 1 then < Display the value of b 528 >;
    if b then
      begin change_if_limit(else_code, save_cond_ptr); return; { wait for \else or \fi }
    end;
    < Skip to \else or \fi, then goto common_ending 526 >;
  common_ending : if cur_chr = fi_code then < Pop the condition stack 522 >
    else if_limit  $\leftarrow$  fi_code; { wait for \fi }
  exit : end;

```

525. In a construction like ‘\if\iftrue abc\else d\fi’, the first \else that we come to after learning that the \if is false is not the \else we’re looking for. Hence the following curious logic is needed.

526. \langle Skip to `\else` or `\fi`, then `goto common_ending 526` $\rangle \equiv$

```

loop begin pass_text;
  if cond_ptr = save_cond_ptr then
    begin if cur_chr  $\neq$  or_code then goto common_ending;
    print_err("Extra_"); print_esc("or");
    help1("I'm_ignoring_this;_it_doesn't_match_any_if."); error;
    end
  else if cur_chr = fi_code then  $\langle$  Pop the condition stack 522  $\rangle$ ;
  end
end

```

This code is used in section 524.

527. \langle Either process `\ifcase` or set b to the value of a boolean condition 527 $\rangle \equiv$

```

case this_if of
  if_char_code, if_cat_code:  $\langle$  Test if two characters match 532  $\rangle$ ;
  if_int_code, if_dim_code:  $\langle$  Test relation between integers or dimensions 529  $\rangle$ ;
  if_odd_code:  $\langle$  Test if an integer is odd 530  $\rangle$ ;
  if_vmode_code:  $b \leftarrow (abs(mode) = vmode)$ ;
  if_hmode_code:  $b \leftarrow (abs(mode) = hmode)$ ;
  if_mmode_code:  $b \leftarrow (abs(mode) = mmode)$ ;
  if_inner_code:  $b \leftarrow (mode < 0)$ ;
  if_void_code, if_hbox_code, if_vbox_code:  $\langle$  Test box register status 531  $\rangle$ ;
  ifx_code:  $\langle$  Test if two tokens match 533  $\rangle$ ;
  if_eof_code: begin scan_four_bit_int;  $b \leftarrow (read\_open[cur\_val] = closed)$ ;
  end;
  if_true_code:  $b \leftarrow true$ ;
  if_false_code:  $b \leftarrow false$ ;
   $\langle$  Cases for conditional 1763  $\rangle$ 
  if_case_code:  $\langle$  Select the appropriate case and return or goto common_ending 535  $\rangle$ ;
  if_pdfprimitive_code: begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  normal; get_next;
    scanner_status  $\leftarrow$  save_scanner_status;
    if cur_cs  $<$  hash_base then  $m \leftarrow prim\_lookup(cur\_cs - single\_base)$ 
    else  $m \leftarrow prim\_lookup(text(cur\_cs))$ ;
     $b \leftarrow ((cur\_cmd \neq undefined\_cs) \wedge (m \neq undefined\_primitive) \wedge (cur\_cmd = prim\_eq\_type(m)) \wedge (cur\_chr = prim\_equiv(m)))$ ;
  end;
end { there are no other cases }

```

This code is used in section 524.

528. \langle Display the value of b 528 $\rangle \equiv$

```

begin begin_diagnostic;
if b then print("{true}") else print("{false}");
end_diagnostic(false);
end

```

This code is used in section 524.

529. Here we use the fact that "<", "=", and ">" are consecutive ASCII codes.

```

⟨Test relation between integers or dimensions 529⟩ ≡
  begin if this_if = if_int_code then scan_int else scan_normal_dimen;
  n ← cur_val; ⟨Get the next non-blank non-call token 432⟩;
  if (cur_tok ≥ other_token + "<") ∧ (cur_tok ≤ other_token + ">") then r ← cur_tok - other_token
  else begin print_err("Missing_ = _inserted_for_"); print_cmd_chr(if_test, this_if);
    help1("I_ was_ expecting_ to_ see_ `<`, _ `=`, _ or_ `>`. _ Didn't."); back_error; r ← "=";
  end;
  if this_if = if_int_code then scan_int else scan_normal_dimen;
  case r of
    "<": b ← (n < cur_val);
    "=": b ← (n = cur_val);
    ">": b ← (n > cur_val);
  end;
end
end

```

This code is used in section 527.

530. ⟨Test if an integer is odd 530⟩ ≡

```

  begin scan_int; b ← odd(cur_val);
end

```

This code is used in section 527.

531. ⟨Test box register status 531⟩ ≡

```

  begin scan_register_num; fetch_box(p);
  if this_if = if_void_code then b ← (p = null)
  else if p = null then b ← false
    else if this_if = if_hbox_code then b ← (type(p) = hlist_node)
      else b ← (type(p) = vlist_node);
  end
end

```

This code is used in section 527.

532. An active character will be treated as category 13 following `\if\noexpand` or following `\ifcat\noexpand.` We use the fact that active characters have the smallest tokens, among all control sequences.

```

define get_x_token_or_active_char  $\equiv$ 
  begin get_x_token;
  if cur_cmd = relax then
    if cur_chr = no_expand_flag then
      begin cur_cmd  $\leftarrow$  active_char; cur_chr  $\leftarrow$  cur_tok - cs_token_flag - active_base;
      end;
    end
  end

<Test if two characters match 532>  $\equiv$ 
begin get_x_token_or_active_char;
if (cur_cmd > active_char)  $\vee$  (cur_chr > 255) then { not a character }
  begin m  $\leftarrow$  relax; n  $\leftarrow$  256;
  end
else begin m  $\leftarrow$  cur_cmd; n  $\leftarrow$  cur_chr;
  end;
get_x_token_or_active_char;
if (cur_cmd > active_char)  $\vee$  (cur_chr > 255) then
  begin cur_cmd  $\leftarrow$  relax; cur_chr  $\leftarrow$  256;
  end;
if this_if = if_char_code then b  $\leftarrow$  (n = cur_chr) else b  $\leftarrow$  (m = cur_cmd);
end

```

This code is used in section 527.

533. Note that ‘`\ifx`’ will declare two macros different if one is *long* or *outer* and the other isn’t, even though the texts of the macros are the same.

We need to reset *scanner_status*, since `\outer` control sequences are allowed, but we might be scanning a macro definition or preamble.

```

<Test if two tokens match 533>  $\equiv$ 
begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  normal; get_next; n  $\leftarrow$  cur_cs;
p  $\leftarrow$  cur_cmd; q  $\leftarrow$  cur_chr; get_next;
if cur_cmd  $\neq$  p then b  $\leftarrow$  false
else if cur_cmd < call then b  $\leftarrow$  (cur_chr = q)
  else <Test if two macro texts match 534>;
  scanner_status  $\leftarrow$  save_scanner_status;
end

```

This code is used in section 527.

534. Note also that ‘\ifx’ decides that macros \a and \b are different in examples like this:

```
\def\a{\c}      \def\c{}
\def\b{\d}      \def\d{}
```

⟨Test if two macro texts match 534⟩ ≡

```
begin p ← link(cur_chr); q ← link(equiv(n)); {omit reference counts}
if p = q then b ← true
else begin while (p ≠ null) ∧ (q ≠ null) do
    if info(p) ≠ info(q) then p ← null
    else begin p ← link(p); q ← link(q);
        end;
    b ← ((p = null) ∧ (q = null));
end;
end
```

This code is used in section 533.

535. ⟨Select the appropriate case and return or goto common_ending 535⟩ ≡

```
begin scan_int; n ← cur_val; {n is the number of cases to pass}
if tracing_commands > 1 then
    begin begin_diagnostic; print("{case_"); print_int(n); print_char("}"); end_diagnostic(false);
    end;
while n ≠ 0 do
    begin pass_text;
    if cond_ptr = save_cond_ptr then
        if cur_chr = or_code then decr(n)
        else goto common_ending
    else if cur_chr = fi_code then ⟨Pop the condition stack 522⟩;
    end;
    change_if_limit(or_code, save_cond_ptr); return; {wait for \or, \else, or \fi}
end
```

This code is used in section 527.

536. The processing of conditionals is complete except for the following code, which is actually part of *expand*. It comes into play when \or, \else, or \fi is scanned.

⟨Terminate the current conditional and skip to \fi 536⟩ ≡

```
begin if tracing_ifs > 0 then
    if tracing_commands ≤ 1 then show_cur_cmd_chr;
if cur_chr > if_limit then
    if if_limit = if_code then insert_relax {condition not yet evaluated}
    else begin print_err("Extra_"); print_cmd_chr(fi_or_else, cur_chr);
        help1("I'm ignoring this; it doesn't match any \if."); error;
    end
else begin while cur_chr ≠ fi_code do pass_text; {skip to \fi}
    ⟨Pop the condition stack 522⟩;
    end;
end
```

This code is used in section 391.

537. File names. It's time now to fret about file names. Besides the fact that different operating systems treat files in different ways, we must cope with the fact that completely different naming conventions are used by different groups of people. The following programs show what is required for one particular operating system; similar routines for other systems are not difficult to devise.

TeX assumes that a file name has three parts: the name proper; its “extension”; and a “file area” where it is found in an external file system. The extension of an input file or a write file is assumed to be `.tex` unless otherwise specified; it is `.log` on the transcript file that records each run of TeX; it is `.tfm` on the font metric files that describe characters in the fonts TeX uses; it is `.dvi` on the output files that specify typesetting information; and it is `.fmt` on the format files written by INITEX to initialize TeX. The file area can be arbitrary on input files, but files are usually output to the user's current area. If an input file cannot be found on the specified area, TeX will look for it on a special system area; this special area is intended for commonly used input files like `webmac.tex`.

Simple uses of TeX refer only to file names that have no explicit extension or area. For example, a person usually says `\input paper` or `\font\tenrm = helvetica` instead of `\input paper.new` or `\font\tenrm = <csd.knuth>test`. Simple file names are best, because they make the TeX source files portable; whenever a file name consists entirely of letters and digits, it should be treated in the same way by all implementations of TeX. However, users need the ability to refer to other files in their environment, especially when responding to error messages concerning unopenable files; therefore we want to let them use the syntax that appears in their favorite operating system.

The following procedures don't allow spaces to be part of file names; but some users seem to like names that are spaced-out. System-dependent changes to allow such things should probably be made with reluctance, and only when an entire file name that includes spaces is “quoted” somehow.

538. In order to isolate the system-dependent aspects of file names, the system-independent parts of TeX are expressed in terms of three system-dependent procedures called *begin_name*, *more_name*, and *end_name*. In essence, if the user-specified characters of the file name are $c_1 \dots c_n$, the system-independent driver program does the operations

$$begin_name; more_name(c_1); \dots; more_name(c_n); end_name.$$

These three procedures communicate with each other via global variables. Afterwards the file name will appear in the string pool as three strings called *cur_name*, *cur_area*, and *cur_ext*; the latter two are null (i.e., `""`), unless they were explicitly specified by the user.

Actually the situation is slightly more complicated, because TeX needs to know when the file name ends. The *more_name* routine is a function (with side effects) that returns *true* on the calls *more_name*(c_1), ..., *more_name*(c_{n-1}). The final call *more_name*(c_n) returns *false*; or, it returns *true* and the token following c_n is something like `\hbox` (i.e., not a character). In other words, *more_name* is supposed to return *true* unless it is sure that the file name has been completely scanned; and *end_name* is supposed to be able to finish the assembly of *cur_name*, *cur_area*, and *cur_ext* regardless of whether *more_name*(c_n) returned *true* or *false*.

{Global variables 13} +=

```
cur_name: str_number; { name of file just scanned }
cur_area: str_number; { file area just scanned, or "" }
cur_ext: str_number; { file extension just scanned, or "" }
```

539. The file names we shall deal with for illustrative purposes have the following structure: If the name contains ‘>’ or ‘:’, the file area consists of all characters up to and including the final such character; otherwise the file area is null. If the remaining file name contains ‘.’, the file extension consists of all such characters from the first remaining ‘.’ to the end, otherwise the file extension is null.

We can scan such file names easily by using two global variables that keep track of the occurrences of area and extension delimiters:

```

⟨Global variables 13⟩ +≡
area_delimiter: pool_pointer; { the most recent ‘>’ or ‘:’, if any }
ext_delimiter: pool_pointer; { the relevant ‘.’, if any }

```

540. Input files that can’t be found in the user’s area may appear in a standard system area called *TEX_area*. Font metric files whose areas are not given explicitly are assumed to appear in a standard system area called *TEX_font_area*. These system area names will, of course, vary from place to place.

```

define TEX_area ≡ "TeXinputs:"
define TEX_font_area ≡ "TeXfonts:"

```

541. Here now is the first of the system-dependent routines for file name scanning.

```

procedure begin_name;
begin area_delimiter ← 0; ext_delimiter ← 0;
end;

```

542. And here’s the second. The string pool might change as the file name is being scanned, since a new \csname might be entered; therefore we keep *area_delimiter* and *ext_delimiter* relative to the beginning of the current string, instead of assigning an absolute address like *pool_ptr* to them.

```

function more_name(c: ASCII_code): boolean;
begin if c = "␣" then more_name ← false
else begin str_room(1); append_char(c); { contribute c to the current string }
if (c = ">") ∨ (c = ":") then
begin area_delimiter ← cur_length; ext_delimiter ← 0;
end
else if (c = ".") ∧ (ext_delimiter = 0) then ext_delimiter ← cur_length;
more_name ← true;
end;
end;
end;

```

543. The third.

```

procedure end_name;
begin if str_ptr + 3 > max_strings then overflow("number_of_strings", max_strings - init_str_ptr);
if area_delimiter = 0 then cur_area ← ""
else begin cur_area ← str_ptr; str_start[str_ptr + 1] ← str_start[str_ptr] + area_delimiter; incr(str_ptr);
end;
if ext_delimiter = 0 then
begin cur_ext ← ""; cur_name ← make_string;
end
else begin cur_name ← str_ptr;
str_start[str_ptr + 1] ← str_start[str_ptr] + ext_delimiter - area_delimiter - 1; incr(str_ptr);
cur_ext ← make_string;
end;
end;
end;

```


544. Conversely, here is a routine that takes three strings and prints a file name that might have produced them. (The routine is system dependent, because some operating systems put the file area last instead of first.)

⟨Basic printing procedures 57⟩ +≡

```
procedure print_file_name(n, a, e : integer);
  begin slow_print(a); slow_print(n); slow_print(e);
  end;
```

545. Another system-dependent routine is needed to convert three internal TeX strings into the *name_of_file* value that is used to open files. The present code allows both lowercase and uppercase letters in the file name.

```
define append_to_name(#) ≡
  begin c ← #; incr(k);
  if k ≤ file_name_size then name_of_file[k] ← xchr[c];
  end

procedure pack_file_name(n, a, e : str_number);
  var k: integer; { number of positions filled in name_of_file }
  c: ASCII_code; { character being packed }
  j: pool_pointer; { index into str_pool }
  begin k ← 0;
  for j ← str_start[a] to str_start[a + 1] − 1 do append_to_name(so(str_pool[j]));
  for j ← str_start[n] to str_start[n + 1] − 1 do append_to_name(so(str_pool[j]));
  for j ← str_start[e] to str_start[e + 1] − 1 do append_to_name(so(str_pool[j]));
  if k ≤ file_name_size then name_length ← k else name_length ← file_name_size;
  for k ← name_length + 1 to file_name_size do name_of_file[k] ← ‘␣’;
  end;
```

546. A messier routine is also needed, since format file names must be scanned before TeX’s string mechanism has been initialized. We shall use the global variable *TEX_format_default* to supply the text for default system areas and extensions related to format files.

```
define format_default_length = 20 { length of the TEX_format_default string }
define format_area_length = 11 { length of its area part }
define format_ext_length = 4 { length of its ‘.fmt’ part }
define format_extension = “.fmt” { the extension, as a WEB constant }

⟨Global variables 13⟩ +≡
TEX_format_default: packed array [1 .. format_default_length] of char;
```

547. ⟨Set initial values of key variables 21⟩ +≡
TEX_format_default ← ‘TeXformats:plain.fmt’;

548. ⟨Check the “constant” values for consistency 14⟩ +≡
if *format_default_length* > *file_name_size* **then** *bad* ← 31;

549. Here is the messy routine that was just mentioned. It sets *name_of_file* from the first *n* characters of *TEX_format_default*, followed by *buffer[a .. b]*, followed by the last *format_ext_length* characters of *TEX_format_default*.

We dare not give error messages here, since T_EX calls this routine before the *error* routine is ready to roll. Instead, we simply drop excess characters, since the error will be detected in another way when a strange file name isn't found.

```
procedure pack_buffered_name(n : small_number; a, b : integer);
  var k: integer; { number of positions filled in name_of_file }
      c: ASCII_code; { character being packed }
      j: integer; { index into buffer or TEX_format_default }
  begin if n + b - a + 1 + format_ext_length > file_name_size then
    b ← a + file_name_size - n - 1 - format_ext_length;
  k ← 0;
  for j ← 1 to n do append_to_name(xord[TEX_format_default[j]]);
  for j ← a to b do append_to_name(buffer[j]);
  for j ← format_default_length - format_ext_length + 1 to format_default_length do
    append_to_name(xord[TEX_format_default[j]]);
  if k ≤ file_name_size then name_length ← k else name_length ← file_name_size;
  for k ← name_length + 1 to file_name_size do name_of_file[k] ← '␣';
  end;
```

550. Here is the only place we use *pack_buffered_name*. This part of the program becomes active when a “virgin” T_EX is trying to get going, just after the preliminary initialization, or when the user is substituting another format file by typing ‘&’ after the initial ‘**’ prompt. The buffer contains the first line of input in *buffer[loc .. (last - 1)]*, where *loc* < *last* and *buffer[loc]* ≠ “␣”.

⟨Declare the function called *open_fmt_file* 550⟩ ≡

```
function open_fmt_file: boolean;
  label found, exit;
  var j: 0 .. buf_size; { the first space after the format file name }
  begin j ← loc;
  if buffer[loc] = "&" then
    begin incr(loc); j ← loc; buffer[last] ← "␣";
    while buffer[j] ≠ "␣" do incr(j);
    pack_buffered_name(0, loc, j - 1); { try first without the system file area }
    if w_open_in(fmt_file) then goto found;
    pack_buffered_name(format_area_length, loc, j - 1); { now try the system format file area }
    if w_open_in(fmt_file) then goto found;
    wake_up_terminal; wterm_ln('Sorry, I␣can'␣t␣find␣that␣format; ', '␣will␣try␣PLAIN. ');
    update_terminal;
  end; { now pull out all the stops: try for the system plain file }
  pack_buffered_name(format_default_length - format_ext_length, 1, 0);
  if ¬w_open_in(fmt_file) then
    begin wake_up_terminal; wterm_ln('I␣can'␣t␣find␣the␣PLAIN␣format␣file! ');
    open_fmt_file ← false; return;
  end;
  found: loc ← j; open_fmt_file ← true;
  exit: end;
```

This code is used in section 1479.

551. Operating systems often make it possible to determine the exact name (and possible version number) of a file that has been opened. The following routine, which simply makes a TeX string from the value of *name_of_file*, should ideally be changed to deduce the full name of file *f*, which is the file most recently opened, if it is possible to do this in a Pascal program.

This routine might be called after string memory has overflowed, hence we dare not use ‘*str_room*’.

```
function make_name_string: str_number;
  var k: 1 .. file_name_size; { index into name_of_file }
  begin if (pool_ptr + name_length > pool_size)  $\vee$  (str_ptr = max_strings)  $\vee$  (cur_length > 0) then
    make_name_string  $\leftarrow$  "?"
  else begin for k  $\leftarrow$  1 to name_length do append_char(xord[name_of_file[k]]);
    make_name_string  $\leftarrow$  make_string;
  end;
end;
function a_make_name_string(var f : alpha_file): str_number;
  begin a_make_name_string  $\leftarrow$  make_name_string;
end;
function b_make_name_string(var f : byte_file): str_number;
  begin b_make_name_string  $\leftarrow$  make_name_string;
end;
function w_make_name_string(var f : word_file): str_number;
  begin w_make_name_string  $\leftarrow$  make_name_string;
end;
```

552. Now let’s consider the “driver” routines by which TeX deals with file names in a system-independent manner. First comes a procedure that looks for a file name in the input by calling *get_x.token* for the information.

```
procedure scan_file_name;
  label done;
  begin name_in_progress  $\leftarrow$  true; begin_name; { Get the next non-blank non-call token 432 };
  loop begin if (cur_cmd > other_char)  $\vee$  (cur_chr > 255) then { not a character }
    begin back_input; goto done;
  end;
  if  $\neg$ more_name(cur_chr) then goto done;
  get_x.token;
end;
done: end_name; name_in_progress  $\leftarrow$  false;
end;
```

553. The global variable *name_in_progress* is used to prevent recursive use of *scan_file_name*, since the *begin_name* and other procedures communicate via global variables. Recursion would arise only by devious tricks like ‘\input\input f’; such attempts at sabotage must be thwarted. Furthermore, *name_in_progress* prevents \input from being initiated when a font size specification is being scanned.

Another global variable, *job_name*, contains the file name that was first \input by the user. This name is extended by ‘.log’ and ‘.dvi’ and ‘.fmt’ in the names of TeX’s output files.

```
{ Global variables 13 } + $\equiv$ 
name_in_progress: boolean; { is a file name being scanned? }
job_name: str_number; { principal file name }
log_opened: boolean; { has the transcript file been opened? }
```

554. Initially *job_name* = 0; it becomes nonzero as soon as the true name is known. We have *job_name* = 0 if and only if the ‘log’ file has not been opened, except of course for a short time just after *job_name* has become nonzero.

⟨Initialize the output routines 55⟩ +≡
job_name ← 0; *name_in_progress* ← false; *log_opened* ← false;

555. Here is a routine that manufactures the output file names, assuming that *job_name* ≠ 0. It ignores and changes the current settings of *cur_area* and *cur_ext*.

```
define pack_cur_name ≡ pack_file_name(cur_name, cur_area, cur_ext)
procedure pack_job_name(s : str_number); { s = ".log", ".dvi", or format_extension }
begin cur_area ← ""; cur_ext ← s; cur_name ← job_name; pack_cur_name;
end;
```

556. If some trouble arises when TeX tries to open a file, the following routine calls upon the user to supply another file name. Parameter *s* is used in the error message to identify the type of file; parameter *e* is the default extension if none is given. Upon exit from the routine, variables *cur_name*, *cur_area*, *cur_ext*, and *name_of_file* are ready for another attempt at file opening.

```
procedure prompt_file_name(s, e : str_number);
label done;
var k: 0 .. buf_size; { index into buffer }
begin if interaction = scroll_mode then wake_up_terminal;
if s = "input_file_name" then print_err("I can't find file `");
else print_err("I can't write on file `");
print_file_name(cur_name, cur_area, cur_ext); print("`.");
if e = ".tex" then show_context;
print_nl("Please type another"); print(s);
if interaction < scroll_mode then fatal_error("***_(job_aborted, file_error_in_nonstop_mode)");
clear_terminal; prompt_input(":"); ⟨Scan file name in the buffer 557⟩;
if cur_ext = "" then cur_ext ← e;
pack_cur_name;
end;
```

557. ⟨Scan file name in the buffer 557⟩ ≡
begin *begin_name*; *k* ← first;
while (*buffer*[*k*] = " ") ∧ (*k* < last) do incr(*k*);
loop begin if *k* = last then goto done;
if ¬more_name(*buffer*[*k*]) then goto done;
incr(*k*);
end;
done: end_name;
end

This code is used in section 556.

558. Here's an example of how these conventions are used. Whenever it is time to ship out a box of stuff, we shall use the macro *ensure_dvi_open*.

```

define ensure_dvi_open  $\equiv$ 
  if output_file_name = 0 then
    begin if job_name = 0 then open_log_file;
    pack_job_name("dvi");
    while  $\neg$ b_open_out(dvi_file) do prompt_file_name("file_name_for_output", "dvi");
    output_file_name  $\leftarrow$  b_make_name_string(dvi_file);
    end
   $\langle$ Global variables 13 $\rangle$   $\equiv$ 
dvi_file: byte_file; { the device-independent output goes here }
output_file_name: str_number; { full name of the output file }
log_name: str_number; { full name of the log file }

```

559. \langle Initialize the output routines 55 \rangle \equiv
output_file_name \leftarrow 0;

560. The *open_log_file* routine is used to open the transcript file and to help it catch up to what has previously been printed on the terminal.

```

procedure open_log_file;
  var old_setting: 0 .. max_selector; { previous selector setting }
  k: 0 .. buf_size; { index into months and buffer }
  l: 0 .. buf_size; { end of first input line }
  months: packed array [1 .. 36] of char; { abbreviations of month names }
  begin old_setting  $\leftarrow$  selector;
  if job_name = 0 then job_name  $\leftarrow$  "texput";
  pack_job_name("log");
  while  $\neg$ a_open_out(log_file) do  $\langle$ Try to get a different log file name 561 $\rangle$ ;
  log_name  $\leftarrow$  a_make_name_string(log_file); selector  $\leftarrow$  log_only; log_opened  $\leftarrow$  true;
   $\langle$ Print the banner line, including the date and time 562 $\rangle$ ;
  input_stack[input_ptr]  $\leftarrow$  cur_input; { make sure bottom level is in memory }
  print_nl("**"); l  $\leftarrow$  input_stack[0].limit_field; { last position of first line }
  if buffer[l] = end_line_char then decr(l);
  for k  $\leftarrow$  1 to l do print(buffer[k]);
  print_ln; { now the transcript file contains the first line of input }
  selector  $\leftarrow$  old_setting + 2; { log_only or term_and_log }
  end;

```

561. Sometimes *open_log_file* is called at awkward moments when TeX is unable to print error messages or even to *show_context*. The *prompt_file_name* routine can result in a *fatal_error*, but the *error* routine will not be invoked because *log_opened* will be false.

The normal idea of *batch_mode* is that nothing at all should be written on the terminal. However, in the unusual case that no log file could be opened, we make an exception and allow an explanatory message to be seen.

Incidentally, the program always refers to the log file as a ‘transcript file’, because some systems cannot use the extension ‘.log’ for this file.

```

 $\langle$ Try to get a different log file name 561 $\rangle$   $\equiv$ 
  begin selector  $\leftarrow$  term_only; prompt_file_name("transcript_file_name", ".log");
  end

```

This code is used in section 560.

562. \langle Print the banner line, including the date and time [562](#) $\rangle \equiv$

```

begin wlog(banner); slow_print(format.ident); print("_"); print_int(sys_day); print_char("_");
months  $\leftarrow$  ^JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC^;
for k  $\leftarrow$  3 * sys_month - 2 to 3 * sys_month do wlog(months[k]);
print_char("_"); print_int(sys_year); print_char("_"); print_two(sys_time div 60); print_char(":");
print_two(sys_time mod 60);
if eTeX_ex then
  begin ; wlog_cr; wlog(^entering_extended_mode^);
  end;
end

```

This code is used in section [560](#).

563. Let's turn now to the procedure that is used to initiate file reading when an '`\input`' command is being processed. Beware: For historic reasons, this code foolishly conserves a tiny bit of string pool space; but that can confuse the interactive 'E' option.

```

procedure start_input; { TEX will \input something }
  label done;
  begin scan_file_name; { set cur_name to desired file name }
  if cur_ext = "" then cur_ext  $\leftarrow$  ".tex";
  pack_cur_name;
  loop begin begin_file_reading; { set up cur_file and new level of input }
    if a_open_in(cur_file) then goto done;
    if cur_area = "" then
      begin pack_file_name(cur_name, TEX_area, cur_ext);
      if a_open_in(cur_file) then goto done;
      end;
    end_file_reading; { remove the level that didn't work }
    prompt_file_name("input_file_name", ".tex");
    end;
done: name  $\leftarrow$  a_make_name_string(cur_file);
if job_name = 0 then
  begin job_name  $\leftarrow$  cur_name; open_log_file;
  end; { open_log_file doesn't show_context, so limit and loc needn't be set to meaningful values yet }
if term_offset + length(name) > max_print_line - 2 then print_ln
else if (term_offset > 0)  $\vee$  (file_offset > 0) then print_char("_");
print_char("("); incr(open_parens); slow_print(name); update_terminal; state  $\leftarrow$  new_line;
if name = str_ptr - 1 then { conserve string pool space (but see note above) }
  begin flush_string; name  $\leftarrow$  cur_name;
  end;
 $\langle$  Read the first line of the new file 564  $\rangle$ ;
end;

```

564. Here we have to remember to tell the *input_ln* routine not to start with a *get*. If the file is empty, it is considered to contain a single blank line.

⟨Read the first line of the new file 564⟩ ≡
 begin *line* ← 1;
 if *input_ln*(*cur_file*, *false*) **then** *do_nothing*;
 firm_up_the_line;
 if *end_line_char_inactive* **then** *decr*(*limit*)
 else *buffer*[*limit*] ← *end_line_char*;
 first ← *limit* + 1; *loc* ← *start*;
 end

This code is used in section 563.

565. Font metric data. TeX gets its knowledge about fonts from font metric files, also called TFM files; the ‘T’ in ‘TFM’ stands for TeX, but other programs know about them too.

The information in a TFM file appears in a sequence of 8-bit bytes. Since the number of bytes is always a multiple of 4, we could also regard the file as a sequence of 32-bit words, but TeX uses the byte interpretation. The format of TFM files was designed by Lyle Ramshaw in 1980. The intent is to convey a lot of different kinds of information in a compact but useful form.

\langle Global variables 13 $\rangle + \equiv$

tfm_file: *byte_file*;

566. The first 24 bytes (6 words) of a TFM file contain twelve 16-bit integers that give the lengths of the various subsequent portions of the file. These twelve integers are, in order:

lf = length of the entire file, in words;
lh = length of the header data, in words;
bc = smallest character code in the font;
ec = largest character code in the font;
nw = number of words in the width table;
nh = number of words in the height table;
nd = number of words in the depth table;
ni = number of words in the italic correction table;
nl = number of words in the lig/kern table;
nk = number of words in the kern table;
ne = number of words in the extensible character table;
np = number of font parameter words.

They are all nonnegative and less than 2^{15} . We must have $bc - 1 \leq ec \leq 255$, and

$$lf = 6 + lh + (ec - bc + 1) + nw + nh + nd + ni + nl + nk + ne + np.$$

Note that a font may contain as many as 256 characters (if $bc = 0$ and $ec = 255$), and as few as 0 characters (if $bc = ec + 1$).

Incidentally, when two or more 8-bit bytes are combined to form an integer of 16 or more bits, the most significant bytes appear first in the file. This is called BigEndian order.

567. The rest of the TFM file may be regarded as a sequence of ten data arrays having the informal specification

```

header : array [0 .. lh - 1] of stuff
char_info : array [bc .. ec] of char_info_word
width : array [0 .. nw - 1] of fix_word
height : array [0 .. nh - 1] of fix_word
depth : array [0 .. nd - 1] of fix_word
italic : array [0 .. ni - 1] of fix_word
lig_kern : array [0 .. nl - 1] of lig_kern_command
kern : array [0 .. nk - 1] of fix_word
exten : array [0 .. ne - 1] of extensible_recipe
param : array [1 .. np] of fix_word

```

The most important data type used here is a *fix_word*, which is a 32-bit representation of a binary fraction. A *fix_word* is a signed quantity, with the two’s complement of the entire word used to represent negation. Of the 32 bits in a *fix_word*, exactly 12 are to the left of the binary point; thus, the largest *fix_word* value is $2048 - 2^{-20}$, and the smallest is -2048 . We will see below, however, that all but two of the *fix_word* values must lie between -16 and $+16$.

568. The first data array is a block of header information, which contains general facts about the font. The header must contain at least two words, *header*[0] and *header*[1], whose meaning is explained below. Additional header information of use to other software routines might also be included, but TeX82 does not need to know about such details. For example, 16 more words of header information are in use at the Xerox Palo Alto Research Center; the first ten specify the character coding scheme used (e.g., ‘XEROX text’ or ‘TeX math symbols’), the next five give the font identifier (e.g., ‘HELVETICA’ or ‘CMSY’), and the last gives the “face byte.” The program that converts DVI files to Xerox printing format gets this information by looking at the TFM file, which it needs to read anyway because of other information that is not explicitly repeated in DVI format.

header[0] is a 32-bit check sum that TeX will copy into the DVI output file. Later on when the DVI file is printed, possibly on another computer, the actual font that gets used is supposed to have a check sum that agrees with the one in the TFM file used by TeX. In this way, users will be warned about potential incompatibilities. (However, if the check sum is zero in either the font file or the TFM file, no check is made.) The actual relation between this check sum and the rest of the TFM file is not important; the check sum is simply an identification number with the property that incompatible fonts almost always have distinct check sums.

header[1] is a *fix_word* containing the design size of the font, in units of TeX points. This number must be at least 1.0; it is fairly arbitrary, but usually the design size is 10.0 for a “10 point” font, i.e., a font that was designed to look best at a 10-point size, whatever that really means. When a TeX user asks for a font ‘at δ pt’, the effect is to override the design size and replace it by δ , and to multiply the x and y coordinates of the points in the font image by a factor of δ divided by the design size. *All other dimensions in the TFM file are fix_word numbers in design-size units*, with the exception of *param*[1] (which denotes the slant ratio). Thus, for example, the value of *param*[6], which defines the em unit, is often the *fix_word* value $2^{20} = 1.0$, since many fonts have a design size equal to one em. The other dimensions must be less than 16 design-size units in absolute value; thus, *header*[1] and *param*[1] are the only *fix_word* entries in the whole TFM file whose first byte might be something besides 0 or 255.

569. Next comes the *char_info* array, which contains one *char_info_word* per character. Each word in this part of the file contains six fields packed into four bytes as follows.

first byte: *width_index* (8 bits)

second byte: *height_index* (4 bits) times 16, plus *depth_index* (4 bits)

third byte: *italic_index* (6 bits) times 4, plus *tag* (2 bits)

fourth byte: *remainder* (8 bits)

The actual width of a character is *width*[*width_index*], in design-size units; this is a device for compressing information, since many characters have the same width. Since it is quite common for many characters to have the same height, depth, or italic correction, the TFM format imposes a limit of 16 different heights, 16 different depths, and 64 different italic corrections.

The italic correction of a character has two different uses. (a) In ordinary text, the italic correction is added to the width only if the TeX user specifies ‘\’ after the character. (b) In math formulas, the italic correction is always added to the width, except with respect to the positioning of subscripts.

Incidentally, the relation *width*[0] = *height*[0] = *depth*[0] = *italic*[0] = 0 should always hold, so that an index of zero implies a value of zero. The *width_index* should never be zero unless the character does not exist in the font, since a character is valid if and only if it lies between *bc* and *ec* and has a nonzero *width_index*.

570. The *tag* field in a *char_info_word* has four values that explain how to interpret the *remainder* field.

tag = 0 (*no_tag*) means that *remainder* is unused.

tag = 1 (*lig_tag*) means that this character has a ligature/kerning program starting at position *remainder* in the *lig_kern* array.

tag = 2 (*list_tag*) means that this character is part of a chain of characters of ascending sizes, and not the largest in the chain. The *remainder* field gives the character code of the next larger character.

tag = 3 (*ext_tag*) means that this character code represents an extensible character, i.e., a character that is built up of smaller pieces so that it can be made arbitrarily large. The pieces are specified in *exten[remainder]*.

Characters with *tag* = 2 and *tag* = 3 are treated as characters with *tag* = 0 unless they are used in special circumstances in math formulas. For example, the `\sum` operation looks for a *list_tag*, and the `\left` operation looks for both *list_tag* and *ext_tag*.

define *no_tag* = 0 { vanilla character }

define *lig_tag* = 1 { character has a ligature/kerning program }

define *list_tag* = 2 { character has a successor in a charlist }

define *ext_tag* = 3 { character is extensible }

571. The *lig_kern* array contains instructions in a simple programming language that explains what to do for special letter pairs. Each word in this array is a *lig_kern_command* of four bytes.

first byte: *skip_byte*, indicates that this is the final program step if the byte is 128 or more, otherwise the next step is obtained by skipping this number of intervening steps.

second byte: *next_char*, “if *next_char* follows the current character, then perform the operation and stop, otherwise continue.”

third byte: *op_byte*, indicates a ligature step if less than 128, a kern step otherwise.

fourth byte: *remainder*.

In a kern step, an additional space equal to $\text{kern}[256 * (\text{op_byte} - 128) + \text{remainder}]$ is inserted between the current character and *next_char*. This amount is often negative, so that the characters are brought closer together by kerning; but it might be positive.

There are eight kinds of ligature steps, having *op_byte* codes $4a + 2b + c$ where $0 \leq a \leq b + c$ and $0 \leq b, c \leq 1$. The character whose code is *remainder* is inserted between the current character and *next_char*; then the current character is deleted if $b = 0$, and *next_char* is deleted if $c = 0$; then we pass over a characters to reach the next current character (which may have a ligature/kerning program of its own).

If the very first instruction of the *lig_kern* array has *skip_byte* = 255, the *next_char* byte is the so-called boundary character of this font; the value of *next_char* need not lie between bc and ec . If the very last instruction of the *lig_kern* array has *skip_byte* = 255, there is a special ligature/kerning program for a boundary character at the left, beginning at location $256 * \text{op_byte} + \text{remainder}$. The interpretation is that TeX puts implicit boundary characters before and after each consecutive string of characters from the same font. These implicit characters do not appear in the output, but they can affect ligatures and kerning.

If the very first instruction of a character’s *lig_kern* program has *skip_byte* > 128, the program actually begins in location $256 * \text{op_byte} + \text{remainder}$. This feature allows access to large *lig_kern* arrays, because the first instruction must otherwise appear in a location ≤ 255 .

Any instruction with *skip_byte* > 128 in the *lig_kern* array must satisfy the condition

$$256 * \text{op_byte} + \text{remainder} < nl.$$

If such an instruction is encountered during normal program execution, it denotes an unconditional halt; no ligature or kerning command is performed.

```

define stop_flag  $\equiv qi(128)$  { value indicating ‘STOP’ in a lig/kern program }
define kern_flag  $\equiv qi(128)$  { op code for a kern step }
define skip_byte( $\#$ )  $\equiv \#.b0$ 
define next_char( $\#$ )  $\equiv \#.b1$ 
define op_byte( $\#$ )  $\equiv \#.b2$ 
define rem_byte( $\#$ )  $\equiv \#.b3$ 

```

572. Extensible characters are specified by an *extensible_recipe*, which consists of four bytes called *top*, *mid*, *bot*, and *rep* (in this order). These bytes are the character codes of individual pieces used to build up a large symbol. If *top*, *mid*, or *bot* are zero, they are not present in the built-up result. For example, an extensible vertical line is like an extensible bracket, except that the top and bottom pieces are missing.

Let T , M , B , and R denote the respective pieces, or an empty box if the piece isn’t present. Then the extensible characters have the form TR^kMR^kB from top to bottom, for some $k \geq 0$, unless M is absent; in the latter case we can have TR^kB for both even and odd values of k . The width of the extensible character is the width of R ; and the height-plus-depth is the sum of the individual height-plus-depths of the components used, since the pieces are butted together in a vertical list.

```

define ext_top( $\#$ )  $\equiv \#.b0$  { top piece in a recipe }
define ext_mid( $\#$ )  $\equiv \#.b1$  { mid piece in a recipe }
define ext_bot( $\#$ )  $\equiv \#.b2$  { bot piece in a recipe }
define ext_rep( $\#$ )  $\equiv \#.b3$  { rep piece in a recipe }

```

573. The final portion of a TFM file is the *param* array, which is another sequence of *fix_word* values.

param[1] = *slant* is the amount of italic slant, which is used to help position accents. For example, *slant* = .25 means that when you go up one unit, you also go .25 units to the right. The *slant* is a pure number; it's the only *fix_word* other than the design size itself that is not scaled by the design size.

param[2] = *space* is the normal spacing between words in text. Note that character "␣" in the font need not have anything to do with blank spaces.

param[3] = *space_stretch* is the amount of glue stretching between words.

param[4] = *space_shrink* is the amount of glue shrinking between words.

param[5] = *x_height* is the size of one ex in the font; it is also the height of letters for which accents don't have to be raised or lowered.

param[6] = *quad* is the size of one em in the font.

param[7] = *extra_space* is the amount added to *param*[2] at the ends of sentences.

If fewer than seven parameters are present, TeX sets the missing parameters to zero. Fonts used for math symbols are required to have additional parameter information, which is explained later.

```

define slant_code = 1
define space_code = 2
define space_stretch_code = 3
define space_shrink_code = 4
define x_height_code = 5
define quad_code = 6
define extra_space_code = 7

```

574. So that is what TFM files hold. Since TeX has to absorb such information about lots of fonts, it stores most of the data in a large array called *font_info*. Each item of *font_info* is a *memory_word*; the *fix_word* data gets converted into *scaled* entries, while everything else goes into words of type *four_quarters*.

When the user defines `\font\font`, say, TeX assigns an internal number to the user's font `\font`. Adding this number to *font_id_base* gives the *eqtb* location of a "frozen" control sequence that will always select the font.

⟨Types in the outer block 18⟩ +≡

```

internal_font_number = font_base .. font_max; { font in a char_node }
font_index = 0 .. font_mem_size; { index into font_info }

```

575. Here now is the (rather formidable) array of font arrays.

```

define non_char  $\equiv$  qi(256) { a halfword code that can't match a real character }
define non_address = 0 { a spurious bchar_label }

(Global variables 13) +=
font_info: array [font_index] of memory_word; { the big collection of font data }
fmem_ptr: font_index; { first unused word of font_info }
font_ptr: internal_font_number; { largest internal font number in use }
font_check: array [internal_font_number] of four_quarters; { check sum }
font_size: array [internal_font_number] of scaled; { "at" size }
font_dsize: array [internal_font_number] of scaled; { "design" size }
font_params: array [internal_font_number] of font_index; { how many font parameters are present }
font_name: array [internal_font_number] of str_number; { name of the font }
font_area: array [internal_font_number] of str_number; { area of the font }
font_bc: array [internal_font_number] of eight_bits; { beginning (smallest) character code }
font_ec: array [internal_font_number] of eight_bits; { ending (largest) character code }
font_glue: array [internal_font_number] of pointer;
    { glue specification for interword space, null if not allocated }
font_used: array [internal_font_number] of boolean;
    { has a character from this font actually appeared in the output? }
hyphen_char: array [internal_font_number] of integer; { current \hyphenchar values }
skew_char: array [internal_font_number] of integer; { current \skewchar values }
bchar_label: array [internal_font_number] of font_index;
    { start of lig_kern program for left boundary character, non_address if there is none }
font_bchar: array [internal_font_number] of min_quarterword .. non_char;
    { boundary character, non_char if there is none }
font_false_bchar: array [internal_font_number] of min_quarterword .. non_char;
    { font_bchar if it doesn't exist in the font, otherwise non_char }

```

576. Besides the arrays just enumerated, we have directory arrays that make it easy to get at the individual entries in *font_info*. For example, the *char_info* data for character *c* in font *f* will be in *font_info*[*char_base*[*f*] + *c*].*qqqq*; and if *w* is the *width_index* part of this word (the *b0* field), the width of the character is *font_info*[*width_base*[*f*] + *w*].*sc*. (These formulas assume that *min_quarterword* has already been added to *c* and to *w*, since TeX stores its quarterwords that way.)

```

(Global variables 13) +=
char_base: array [internal_font_number] of integer; { base addresses for char_info }
width_base: array [internal_font_number] of integer; { base addresses for widths }
height_base: array [internal_font_number] of integer; { base addresses for heights }
depth_base: array [internal_font_number] of integer; { base addresses for depths }
italic_base: array [internal_font_number] of integer; { base addresses for italic corrections }
lig_kern_base: array [internal_font_number] of integer; { base addresses for ligature/kerning programs }
kern_base: array [internal_font_number] of integer; { base addresses for kerns }
exten_base: array [internal_font_number] of integer; { base addresses for extensible recipes }
param_base: array [internal_font_number] of integer; { base addresses for font parameters }

```

577. (Set initial values of key variables 21) +=

```

for k  $\leftarrow$  font_base to font_max do font_used[k]  $\leftarrow$  false;

```

578. T_EX always knows at least one font, namely the null font. It has no characters, and its seven parameters are all equal to zero.

⟨ Initialize table entries (done by INITEX only) 182 ⟩ +≡
font_ptr ← *null_font*; *fmem_ptr* ← 7; *font_name*[*null_font*] ← "nullfont"; *font_area*[*null_font*] ← "";
hyphen_char[*null_font*] ← "-"; *skew_char*[*null_font*] ← -1; *bchar_label*[*null_font*] ← *non_address*;
font_bchar[*null_font*] ← *non_char*; *font_false_bchar*[*null_font*] ← *non_char*; *font_bc*[*null_font*] ← 1;
font_ec[*null_font*] ← 0; *font_size*[*null_font*] ← 0; *font_dsize*[*null_font*] ← 0; *char_base*[*null_font*] ← 0;
width_base[*null_font*] ← 0; *height_base*[*null_font*] ← 0; *depth_base*[*null_font*] ← 0;
italic_base[*null_font*] ← 0; *lig_kern_base*[*null_font*] ← 0; *kern_base*[*null_font*] ← 0;
exten_base[*null_font*] ← 0; *font_glue*[*null_font*] ← *null*; *font_params*[*null_font*] ← 7;
param_base[*null_font*] ← -1;
for *k* ← 0 **to** 6 **do** *font_info*[*k*].*sc* ← 0;

579. ⟨ Put each of T_EX's primitives into the hash table 244 ⟩ +≡
primitive("nullfont", *set_font*, *null_font*); *text*(*frozen_null_font*) ← "nullfont";
eqtb[*frozen_null_font*] ← *eqtb*[*cur_val*];

580. Of course we want to define macros that suppress the detail of how font information is actually packed, so that we don't have to write things like

$$font_info[width_base[f] + font_info[char_base[f] + c].qqqq.b0].sc$$

too often. The WEB definitions here make $char_info(f)(c)$ the *four_quarters* word of font information corresponding to character c of font f . If q is such a word, $char_width(f)(q)$ will be the character's width; hence the long formula above is at least abbreviated to

$$char_width(f)(char_info(f)(c)).$$

Usually, of course, we will fetch q first and look at several of its fields at the same time.

The italic correction of a character will be denoted by $char_italic(f)(q)$, so it is analogous to $char_width$. But we will get at the height and depth in a slightly different way, since we usually want to compute both height and depth if we want either one. The value of $height_depth(q)$ will be the 8-bit quantity

$$b = height_index \times 16 + depth_index,$$

and if b is such a byte we will write $char_height(f)(b)$ and $char_depth(f)(b)$ for the height and depth of the character c for which $q = char_info(f)(c)$. Got that?

The tag field will be called $char_tag(q)$; the remainder byte will be called $rem_byte(q)$, using a macro that we have already defined above.

Access to a character's *width*, *height*, *depth*, and *tag* fields is part of TeX's inner loop, so we want these macros to produce code that is as fast as possible under the circumstances.

```

define char_info_end(#)  $\equiv$  # ] .qqqq
define char_info(#)  $\equiv$  font_info [ char_base[#] + char_info_end
define char_width_end(#)  $\equiv$  #.b0 ] .sc
define char_width(#)  $\equiv$  font_info [ width_base[#] + char_width_end
define char_exists(#)  $\equiv$  (#.b0 > min_quarterword)
define char_italic_end(#)  $\equiv$  (qo(#.b2)) div 4 ] .sc
define char_italic(#)  $\equiv$  font_info [ italic_base[#] + char_italic_end
define height_depth(#)  $\equiv$  qo(#.b1)
define char_height_end(#)  $\equiv$  (#) div 16 ] .sc
define char_height(#)  $\equiv$  font_info [ height_base[#] + char_height_end
define char_depth_end(#)  $\equiv$  (#) mod 16 ] .sc
define char_depth(#)  $\equiv$  font_info [ depth_base[#] + char_depth_end
define char_tag(#)  $\equiv$  ((qo(#.b2)) mod 4)
```

581. The global variable *null_character* is set up to be a word of *char_info* for a character that doesn't exist. Such a word provides a convenient way to deal with erroneous situations.

⟨Global variables 13⟩ +≡

null_character: *four_quarters*; { nonexistent character information }

582. ⟨Set initial values of key variables 21⟩ +≡

```

null_character.b0  $\leftarrow$  min_quarterword; null_character.b1  $\leftarrow$  min_quarterword;
null_character.b2  $\leftarrow$  min_quarterword; null_character.b3  $\leftarrow$  min_quarterword;
```

583. Here are some macros that help process ligatures and kerns. We write $\text{char_kern}(f)(j)$ to find the amount of kerning specified by kerning command j in font f . If j is the char_info for a character with a ligature/kern program, the first instruction of that program is either $i = \text{font_info}[\text{lig_kern_start}(f)(j)]$ or $\text{font_info}[\text{lig_kern_restart}(f)(i)]$, depending on whether or not $\text{skip_byte}(i) \leq \text{stop_flag}$.

The constant kern_base_offset should be simplified, for Pascal compilers that do not do local optimization.

```

define char_kern_end(#)  $\equiv 256 * \text{op\_byte}(\#) + \text{rem\_byte}(\#)$  ] .sc
define char_kern(#)  $\equiv \text{font\_info}$  [ kern_base[#] + char_kern_end
define kern_base_offset  $\equiv 256 * (128 + \text{min\_quarterword})$ 
define lig_kern_start(#)  $\equiv \text{lig\_kern\_base}[\#] + \text{rem\_byte}$  { beginning of lig/kern program }
define lig_kern_restart_end(#)  $\equiv 256 * \text{op\_byte}(\#) + \text{rem\_byte}(\#) + 32768 - \text{kern\_base\_offset}$ 
define lig_kern_restart(#)  $\equiv \text{lig\_kern\_base}[\#] + \text{lig\_kern\_restart\_end}$ 

```

584. Font parameters are referred to as $\text{slant}(f)$, $\text{space}(f)$, etc.

```

define param_end(#)  $\equiv \text{param\_base}[\#]$  ] .sc
define param(#)  $\equiv \text{font\_info}$  [ # + param_end
define slant  $\equiv \text{param}(\text{slant\_code})$  { slant to the right, per unit distance upward }
define space  $\equiv \text{param}(\text{space\_code})$  { normal space between words }
define space_stretch  $\equiv \text{param}(\text{space\_stretch\_code})$  { stretch between words }
define space_shrink  $\equiv \text{param}(\text{space\_shrink\_code})$  { shrink between words }
define x_height  $\equiv \text{param}(\text{x\_height\_code})$  { one ex }
define quad  $\equiv \text{param}(\text{quad\_code})$  { one em }
define extra_space  $\equiv \text{param}(\text{extra\_space\_code})$  { additional space at end of sentence }

```

⟨ The em width for cur_font 584 ⟩ \equiv
 $\text{quad}(\text{cur_font})$

This code is used in section 481.

585. ⟨ The x-height for cur_font 585 ⟩ \equiv
 $\text{x_height}(\text{cur_font})$

This code is used in section 481.

586. TeX checks the information of a TFM file for validity as the file is being read in, so that no further checks will be needed when typesetting is going on. The somewhat tedious subroutine that does this is called *read_font_info*. It has four parameters: the user font identifier *u*, the file name and area strings *nom* and *aire*, and the “at” size *s*. If *s* is negative, it’s the negative of a scale factor to be applied to the design size; *s* = −1000 is the normal case. Otherwise *s* will be substituted for the design size; in this case, *s* must be positive and less than 2048 pt (i.e., it must be less than 2^{27} when considered as an integer).

The subroutine opens and closes a global file variable called *tfm_file*. It returns the value of the internal font number that was just loaded. If an error is detected, an error message is issued and no font information is stored; *null_font* is returned in this case.

```

define bad_tfm = 11 { label for read_font_info }
define abort  $\equiv$  goto bad_tfm { do this when the TFM data is wrong }

function read_font_info(u : pointer; nom, aire : str_number; s : scaled): internal_font_number;
    { input a TFM file }
label done, bad_tfm, not_found;
var k: font_index; { index into font_info }
    file_opened: boolean; { was tfm_file successfully opened? }
    lf, lh, bc, ec, nw, nh, nd, ni, nl, nk, ne, np: halfword; { sizes of subfiles }
    f: internal_font_number; { the new font’s number }
    g: internal_font_number; { the number to return }
    a, b, c, d: eight_bits; { byte variables }
    qw: four_quarters; sw: scaled; { accumulators }
    bch_label: integer; { left boundary start location, or infinity }
    bchar: 0 .. 256; { boundary character, or 256 }
    z: scaled; { the design size or the “at” size }
    alpha: integer; beta: 1 .. 16; { auxiliary quantities used in fixed-point multiplication }
begin g  $\leftarrow$  null_font;
    < Read and check the font data; abort if the TFM file is malformed; if there’s no room for this font, say so
      and goto done; otherwise incr(font_ptr) and goto done 588 >;
bad_tfm: < Report that the font won’t be loaded 587 >;
done: if file_opened then b_close(tfm_file);
    read_font_info  $\leftarrow$  g;
end;

```

587. There are programs called `TFtoPL` and `PLtoTF` that convert between the TFM format and a symbolic property-list format that can be easily edited. These programs contain extensive diagnostic information, so TEX does not have to bother giving precise details about why it rejects a particular TFM file.

```

define start_font_error_message  $\equiv$  print_err("Font_"); sprint_cs(u); print_char("=");
      print_file_name(nom, aire, "");
      if s  $\geq$  0 then
        begin print("_at_"); print_scaled(s); print("pt");
        end
      else if s  $\neq$  -1000 then
        begin print("_scaled_"); print_int(-s);
        end
<Report that the font won't be loaded 587>  $\equiv$ 
  start_font_error_message;
  if file_opened then print("_not_loadable:_Bad_metric_(TFM)_file")
  else print("_not_loadable:_Metric_(TFM)_file_not_found");
  help5("I_wasn't_able_to_read_the_size_data_for_this_font,")
  ("so_I_will_ignore_the_font_specification.")
  (" [Wizards_can_fix_TFM_files_using_TFtoPL/PLtoTF.]")
  ("You_might_try_inserting_a_different_font_spec;")
  ("e.g.,_type_\I\font<same_font_id>=<substitute_font_name>`."); error

```

This code is used in section 586.

588. <Read and check the font data; *abort* if the TFM file is malformed; if there's no room for this font, say so and **goto** *done*; otherwise *incr*(*font_ptr*) and **goto** *done* 588> \equiv

```

<Open tfm_file for input 589>;
<Read the TFM size fields 591>;
<Use size fields to allocate font information 592>;
<Read the TFM header 594>;
<Read character data 595>;
<Read box dimensions 598>;
<Read ligature/kern program 600>;
<Read extensible character recipes 601>;
<Read font parameters 602>;
<Make final adjustments and goto done 603>

```

This code is used in section 586.

589. <Open *tfm_file* for input 589> \equiv

```

file_opened  $\leftarrow$  false;
if aire = "" then pack_file_name(nom, TEX_font_area, ".tfm")
else pack_file_name(nom, aire, ".tfm");
if  $\neg$ b_open_in(tfm_file) then abort;
file_opened  $\leftarrow$  true

```

This code is used in section 588.

590. Note: A malformed TFM file might be shorter than it claims to be; thus *eof*(*tfm_file*) might be true when *read_font_info* refers to *tfm_file*↑ or when it says *get*(*tfm_file*). If such circumstances cause system error messages, you will have to defeat them somehow, for example by defining *fget* to be ‘**begin** *get*(*tfm_file*); **if** *eof*(*tfm_file*) **then** *abort*; **end**’.

```
define fget  $\equiv$  get(tfm_file)
define fbyte  $\equiv$  tfm_file↑
define read_sixteen(#)  $\equiv$ 
  begin #  $\leftarrow$  fbyte;
  if # > 127 then abort;
  fget; #  $\leftarrow$  # * '400 + fbyte;
  end
define store_four_quarters(#)  $\equiv$ 
  begin fget; a  $\leftarrow$  fbyte; qw.b0  $\leftarrow$  qi(a); fget; b  $\leftarrow$  fbyte; qw.b1  $\leftarrow$  qi(b); fget; c  $\leftarrow$  fbyte;
  qw.b2  $\leftarrow$  qi(c); fget; d  $\leftarrow$  fbyte; qw.b3  $\leftarrow$  qi(d); #  $\leftarrow$  qw;
  end
```

591. ⟨Read the TFM size fields 591⟩ \equiv

```
begin read_sixteen(lf); fget; read_sixteen(lh); fget; read_sixteen(bc); fget; read_sixteen(ec);
if (bc > ec + 1)  $\vee$  (ec > 255) then abort;
if bc > 255 then { bc = 256 and ec = 255 }
  begin bc  $\leftarrow$  1; ec  $\leftarrow$  0;
  end;
fget; read_sixteen(nw); fget; read_sixteen(nh); fget; read_sixteen(nd); fget; read_sixteen(ni); fget;
read_sixteen(nl); fget; read_sixteen(nk); fget; read_sixteen(ne); fget; read_sixteen(np);
if lf  $\neq$  6 + lh + (ec - bc + 1) + nw + nh + nd + ni + nl + nk + ne + np then abort;
if (nw = 0)  $\vee$  (nh = 0)  $\vee$  (nd = 0)  $\vee$  (ni = 0) then abort;
end
```

This code is used in section 588.

592. The preliminary settings of the index-offset variables *char_base*, *width_base*, *lig_kern_base*, *kern_base*, and *exten_base* will be corrected later by subtracting *min_quarterword* from them; and we will subtract 1 from *param_base* too. It's best to forget about such anomalies until later.

⟨Use size fields to allocate font information 592⟩ \equiv

```
lf  $\leftarrow$  lf - 6 - lh; { lf words should be loaded into font_info }
if np < 7 then lf  $\leftarrow$  lf + 7 - np; { at least seven parameters will appear }
if (font_ptr = font_max)  $\vee$  (fmem_ptr + lf > font_mem_size) then
  ⟨Apologize for not loading the font, goto done 593⟩;
f  $\leftarrow$  font_ptr + 1; char_base[f]  $\leftarrow$  fmem_ptr - bc; width_base[f]  $\leftarrow$  char_base[f] + ec + 1;
height_base[f]  $\leftarrow$  width_base[f] + nw; depth_base[f]  $\leftarrow$  height_base[f] + nh;
italic_base[f]  $\leftarrow$  depth_base[f] + nd; lig_kern_base[f]  $\leftarrow$  italic_base[f] + ni;
kern_base[f]  $\leftarrow$  lig_kern_base[f] + nl - kern_base_offset;
exten_base[f]  $\leftarrow$  kern_base[f] + kern_base_offset + nk; param_base[f]  $\leftarrow$  exten_base[f] + ne
```

This code is used in section 588.

593. ⟨Apologize for not loading the font, **goto** *done* 593⟩ \equiv

```
begin start_font_error_message; print("_not_loaded:_Not_enough_room_left");
help4("I'm_afraid_I_won't_be_able_to_make_use_of_this_font,")
("because_my_memory_for_character-size_data_is_too_small.")
("If_you're_really_stuck,_ask_a_wizard_to_enlarge_me.")
("Or_maybe_try_I\font<same_font_id>=<name_of_loaded_font>`."); error; goto done;
end
```

This code is used in section 592.

594. Only the first two words of the header are needed by T_EX82.

```

⟨Read the TFM header 594⟩ ≡
  begin if lh < 2 then abort;
  store_four_quarters(font_check[f]); fget; read_sixteen(z); { this rejects a negative design size }
  fget; z ← z * '400 + fbyte; fget; z ← (z * '20) + (fbyte div '20);
  if z < unity then abort;
  while lh > 2 do
    begin fget; fget; fget; fget; decr(lh); { ignore the rest of the header }
    end;
  font_dsize[f] ← z;
  if s ≠ -1000 then
    if s ≥ 0 then z ← s
    else z ← xn_over_d(z, -s, 1000);
  font_size[f] ← z;
end

```

This code is used in section 588.

```

595. ⟨Read character data 595⟩ ≡
  for k ← fmem_ptr to width_base[f] - 1 do
    begin store_four_quarters(font_info[k].qqqq);
    if (a ≥ nw) ∨ (b div '20 ≥ nh) ∨ (b mod '20 ≥ nd) ∨ (c div 4 ≥ ni) then abort;
    case c mod 4 of
      lig_tag: if d ≥ nl then abort;
      ext_tag: if d ≥ ne then abort;
      list_tag: ⟨Check for charlist cycle 596⟩;
      othercases do_nothing { no_tag }
    endcases;
  end

```

This code is used in section 588.

596. We want to make sure that there is no cycle of characters linked together by *list_tag* entries, since such a cycle would get T_EX into an endless loop. If such a cycle exists, the routine here detects it when processing the largest character code in the cycle.

```

define check_byte_range(#) ≡
  begin if (# < bc) ∨ (# > ec) then abort
  end
define current_character_being_worked_on ≡ k + bc - fmem_ptr
⟨Check for charlist cycle 596⟩ ≡
  begin check_byte_range(d);
  while d < current_character_being_worked_on do
    begin qw ← char_info(f)(d); { N.B.: not qi(d), since char_base[f] hasn't been adjusted yet }
    if char_tag(qw) ≠ list_tag then goto not_found;
    d ← qo(rem_byte(qw)); { next character on the list }
    end;
  if d = current_character_being_worked_on then abort; { yes, there's a cycle }
not_found: end

```

This code is used in section 595.

597. A *fix_word* whose four bytes are (a, b, c, d) from left to right represents the number

$$x = \begin{cases} b \cdot 2^{-4} + c \cdot 2^{-12} + d \cdot 2^{-20}, & \text{if } a = 0; \\ -16 + b \cdot 2^{-4} + c \cdot 2^{-12} + d \cdot 2^{-20}, & \text{if } a = 255. \end{cases}$$

(No other choices of a are allowed, since the magnitude of a number in design-size units must be less than 16.) We want to multiply this quantity by the integer z , which is known to be less than 2^{27} . If $z < 2^{23}$, the individual multiplications $b \cdot z$, $c \cdot z$, $d \cdot z$ cannot overflow; otherwise we will divide z by 2, 4, 8, or 16, to obtain a multiplier less than 2^{23} , and we can compensate for this later. If z has thereby been replaced by $z' = z/2^e$, let $\beta = 2^{4-e}$; we shall compute

$$\lfloor (b + c \cdot 2^{-8} + d \cdot 2^{-16}) z' / \beta \rfloor$$

if $a = 0$, or the same quantity minus $\alpha = 2^{4+e}z'$ if $a = 255$. This calculation must be done exactly, in order to guarantee portability of TeX between computers.

```

define store_scaled(#) ≡
  begin fget; a ← fbyte; fget; b ← fbyte; fget; c ← fbyte; fget; d ← fbyte;
  sw ← (((((d * z) div '400) + (c * z)) div '400) + (b * z)) div beta;
  if a = 0 then # ← sw else if a = 255 then # ← sw - alpha else abort;
  end

function store_scaled_f(sq, z : scaled): scaled;
  var a, b, c, d: eight_bits; sw: scaled; alpha: integer; beta: 1 .. 16;
  begin alpha ← 16;
  if z ≥ '1000000000 then pdf_error("font", "size_is_too_large");
  while z ≥ '40000000 do
    begin z ← z div 2; alpha ← alpha + alpha;
    end;
  beta ← 256 div alpha; alpha ← alpha * z;
  if sq ≥ 0 then
    begin d ← sq mod 256; sq ← sq div 256;
      { any "mod 256" not really needed, would typecast alone be safe? }
    c ← sq mod 256; sq ← sq div 256; b ← sq mod 256; sq ← sq div 256; a ← sq mod 256;
    end
  else begin sq ← (sq + 1073741824) + 1073741824; { braces for optimizing compiler }
    d ← sq mod 256; sq ← sq div 256; c ← sq mod 256; sq ← sq div 256; b ← sq mod 256;
    sq ← sq div 256; a ← (sq + 128) mod 256;
    end;
  sw ← (((((d * z) div '400) + (c * z)) div '400) + (b * z)) div beta;
  if a = 0 then store_scaled_f ← sw else if a = 255 then
    store_scaled_f ← sw - alpha else pdf_error("store_scaled_f", "vf_scaling");
  end;

```

598. $\langle \text{Read box dimensions 598} \rangle \equiv$

```

begin  $\langle \text{Replace } z \text{ by } z' \text{ and compute } \alpha, \beta \text{ 599} \rangle$ ;
for k ← width_base[f] to lig_kern_base[f] - 1 do store_scaled(font_info[k].sc);
if font_info[width_base[f]].sc ≠ 0 then abort; { width[0] must be zero }
if font_info[height_base[f]].sc ≠ 0 then abort; { height[0] must be zero }
if font_info[depth_base[f]].sc ≠ 0 then abort; { depth[0] must be zero }
if font_info[italic_base[f]].sc ≠ 0 then abort; { italic[0] must be zero }
end

```

This code is used in section 588.

599. $\langle \text{Replace } z \text{ by } z' \text{ and compute } \alpha, \beta \text{ 599} \rangle \equiv$

```

begin  $\alpha \leftarrow 16$ ;
if  $z \geq '1000000000$  then  $\text{pdf\_error}(\text{"font"}, \text{"size\_is\_too\_large"})$ ;
while  $z \geq '40000000$  do
  begin  $z \leftarrow z \text{ div } 2$ ;  $\alpha \leftarrow \alpha + \alpha$ ;
  end;
 $\beta \leftarrow 256 \text{ div } \alpha$ ;  $\alpha \leftarrow \alpha * z$ ;
end

```

This code is used in section 598.

600. **define** $\text{check_existence}(\#) \equiv$

```

  begin  $\text{check\_byte\_range}(\#)$ ;  $qw \leftarrow \text{char\_info}(f)(\#)$ ; { N.B.: not  $qi(\#)$  }
  if  $\neg \text{char\_exists}(qw)$  then  $\text{abort}$ ;
  end

```

$\langle \text{Read ligature/kern program 600} \rangle \equiv$

```

 $bch\_label \leftarrow '77777$ ;  $bchar \leftarrow 256$ ;
if  $nl > 0$  then
  begin for  $k \leftarrow \text{lig\_kern\_base}[f]$  to  $\text{kern\_base}[f] + \text{kern\_base\_offset} - 1$  do
    begin  $\text{store\_four\_quarters}(\text{font\_info}[k].qqqq)$ ;
    if  $a > 128$  then
      begin if  $256 * c + d \geq nl$  then  $\text{abort}$ ;
      if  $a = 255$  then
        if  $k = \text{lig\_kern\_base}[f]$  then  $bchar \leftarrow b$ ;
      end
    else begin if  $b \neq bchar$  then  $\text{check\_existence}(b)$ ;
      if  $c < 128$  then  $\text{check\_existence}(d)$  { check ligature }
      else if  $256 * (c - 128) + d \geq nk$  then  $\text{abort}$ ; { check kern }
      if  $a < 128$  then
        if  $k - \text{lig\_kern\_base}[f] + a + 1 \geq nl$  then  $\text{abort}$ ;
      end;
    end;
    if  $a = 255$  then  $bch\_label \leftarrow 256 * c + d$ ;
  end;
  for  $k \leftarrow \text{kern\_base}[f] + \text{kern\_base\_offset}$  to  $\text{exten\_base}[f] - 1$  do  $\text{store\_scaled}(\text{font\_info}[k].sc)$ ;

```

This code is used in section 588.

601. $\langle \text{Read extensible character recipes 601} \rangle \equiv$

```

for  $k \leftarrow \text{exten\_base}[f]$  to  $\text{param\_base}[f] - 1$  do
  begin  $\text{store\_four\_quarters}(\text{font\_info}[k].qqqq)$ ;
  if  $a \neq 0$  then  $\text{check\_existence}(a)$ ;
  if  $b \neq 0$  then  $\text{check\_existence}(b)$ ;
  if  $c \neq 0$  then  $\text{check\_existence}(c)$ ;
   $\text{check\_existence}(d)$ ;
  end

```

This code is used in section 588.

602. We check to see that the TFM file doesn't end prematurely; but no error message is given for files having more than lf words.

```

⟨Read font parameters 602⟩ ≡
  begin for  $k \leftarrow 1$  to  $np$  do
    if  $k = 1$  then { the slant parameter is a pure number }
      begin fget;  $sw \leftarrow fbyte$ ;
      if  $sw > 127$  then  $sw \leftarrow sw - 256$ ;
      fget;  $sw \leftarrow sw * '400 + fbyte$ ; fget;  $sw \leftarrow sw * '400 + fbyte$ ; fget;
      font_info[param_base[f]].sc  $\leftarrow (sw * '20) + (fbyte \text{ div } '20)$ ;
      end
    else store_scaled(font_info[param_base[f] +  $k - 1$ ].sc);
  if eof(tfm_file) then abort;
  for  $k \leftarrow np + 1$  to 7 do font_info[param_base[f] +  $k - 1$ ].sc  $\leftarrow 0$ ;
  end

```

This code is used in section 588.

603. Now to wrap it up, we have checked all the necessary things about the TFM file, and all we need to do is put the finishing touches on the data for the new font.

```

define adjust( $\#$ )  $\equiv \#[f] \leftarrow qo(\#[f])$  { correct for the excess min_quarterword that was added }
⟨Make final adjustments and goto done 603⟩ ≡
  if  $np \geq 7$  then font_params[f]  $\leftarrow np$  else font_params[f]  $\leftarrow 7$ ;
  hyphen_char[f]  $\leftarrow$  default_hyphen_char; skew_char[f]  $\leftarrow$  default_skew_char;
  if bch_label < nl then bchar_label[f]  $\leftarrow$  bch_label + lig_kern_base[f]
  else bchar_label[f]  $\leftarrow$  non_address;
  font_bchar[f]  $\leftarrow qi(bchar)$ ; font_false_bchar[f]  $\leftarrow qi(bchar)$ ;
  if bchar  $\leq ec$  then
    if bchar  $\geq bc$  then
      begin  $qw \leftarrow char\_info(f)(bchar)$ ; { N.B.: not  $qi(bchar)$  }
      if char_exists( $qw$ ) then font_false_bchar[f]  $\leftarrow$  non_char;
      end;
  font_name[f]  $\leftarrow nom$ ; font_area[f]  $\leftarrow aire$ ; font_bc[f]  $\leftarrow bc$ ; font_ec[f]  $\leftarrow ec$ ; font_glue[f]  $\leftarrow null$ ;
  adjust(char_base); adjust(width_base); adjust(lig_kern_base); adjust(kern_base); adjust(exten_base);
  decr(param_base[f]); fmem_ptr  $\leftarrow$  fmem_ptr + lf; font_ptr  $\leftarrow f$ ;  $g \leftarrow f$ ; goto done

```

This code is used in section 588.

604. Before we forget about the format of these tables, let's deal with two of T_EX's basic scanning routines related to font information.

⟨Declare procedures that scan font-related stuff 604⟩ ≡

```
function test_no_ligatures(f : internal_font_number): integer;
  label exit;
  var c: integer;
  begin test_no_ligatures ← 1;
  for c ← font_bc[f] to font_ec[f] do
    if char_exists(orig_char_info(f)(c)) then
      if odd(char_tag(orig_char_info(f)(c))) then
        begin test_no_ligatures ← 0; return;
        end;
  exit: end;
function get_tag_code(f : internal_font_number; c : eight_bits): integer;
  var i: small_number;
  begin if is_valid_char(c) then
    begin i ← char_tag(char_info(f)(c));
    if i = lig_tag then get_tag_code ← 1
    else if i = list_tag then get_tag_code ← 2
    else if i = ext_tag then get_tag_code ← 4
    else get_tag_code ← 0;
    end
  else get_tag_code ← -1;
  end;
procedure scan_font_ident;
  var f: internal_font_number; m: halfword;
  begin ⟨Get the next non-blank non-call token 432⟩;
  if (cur_cmd = def_font) ∨ (cur_cmd = letterspace_font) ∨ (cur_cmd = pdf_copy_font) then f ← cur_font
  else if cur_cmd = set_font then f ← cur_chr
    else if cur_cmd = def_family then
      begin m ← cur_chr; scan_four_bit_int; f ← equiv(m + cur_val);
      end
    else begin print_err("Missing_font_identifier");
      help2("I_was_looking_for_a_control_sequence_whose")
      ("current_meaning_has_been_defined_by_\font."); back_error; f ← null_font;
      end;
    cur_val ← f;
  end;
```

See also section 605.

This code is used in section 435.

605. The following routine is used to implement ‘\fontdimen n f ’. The boolean parameter *writing* is set *true* if the calling program intends to change the parameter value.

```

⟨ Declare procedures that scan font-related stuff 604 ⟩ +≡
procedure find_font_dimen(writing : boolean); { sets cur_val to font_info location }
  var f: internal_font_number; n: integer; { the parameter number }
  begin scan_int; n ← cur_val; scan_font_ident; f ← cur_val;
  if n ≤ 0 then cur_val ← fmem_ptr
  else begin if writing ∧ (n ≤ space_shrink_code) ∧ (n ≥ space_code) ∧ (font_glue[f] ≠ null) then
    begin delete_glue_ref(font_glue[f]); font_glue[f] ← null;
    end;
  if n > font_params[f] then
    if f < font_ptr then cur_val ← fmem_ptr
    else ⟨ Increase the number of parameters in the last font 607 ⟩
    else cur_val ← n + param_base[f];
  end;
  ⟨ Issue an error message if cur_val = fmem_ptr 606 ⟩;
end;

```

606. ⟨ Issue an error message if *cur_val* = *fmem_ptr* 606 ⟩ ≡

```

if cur_val = fmem_ptr then
  begin print_err("Font_"); print_esc(font_id.text(f)); print("_has_only_");
  print_int(font_params[f]); print("_fontdimen_parameters");
  help2("To_increase_the_number_of_font_parameters,you_must")
  ("use_\fontdimen_immediately_after_the_\font_is_loaded."); error;
  end

```

This code is used in section 605.

607. ⟨ Increase the number of parameters in the last font 607 ⟩ ≡

```

begin repeat if fmem_ptr = font_mem_size then overflow("font_memory",font_mem_size);
  font_info[fmem_ptr].sc ← 0; incr(fmem_ptr); incr(font_params[f]);
until n = font_params[f];
cur_val ← fmem_ptr - 1; { this equals param_base[f] + font_params[f] }
end

```

This code is used in section 605.

608. When TeX wants to typeset a character that doesn’t exist, the character node is not created; thus the output routine can assume that characters exist when it sees them. The following procedure prints a warning message unless the user has suppressed it.

```

procedure char_warning(f : internal_font_number; c : eight_bits);
  var old_setting: integer; { saved value of tracing_online }
  begin if tracing_lost_chars > 0 then
    begin old_setting ← tracing_online;
    if eTeX_ex ∧ (tracing_lost_chars > 1) then tracing_online ← 1;
    begin begin_diagnostic; print_nl("Missing_character:_There_is_no_"); print_ASCII(c);
    print("_in_font_"); slow_print(font_name[f]); print_char("!"); end_diagnostic(false);
    end; tracing_online ← old_setting;
    end;
  end;

```

609. Here is a function that returns a pointer to a character node for a given character in a given font. If that character doesn't exist, *null* is returned instead.

```
function new_character(f : internal_font_number; c : eight_bits): pointer;
  label exit;
  var p: pointer; { newly allocated node }
  begin if font_bc[f] ≤ c then
    if font_ec[f] ≥ c then
      if char_exists(char_info(f)(qi(c))) then
        begin p ← get_avail; font(p) ← f; character(p) ← qi(c); new_character ← p; return;
        end;
      char_warning(f, c); new_character ← null;
    exit: end;
```

610. Device-independent file format. The most important output produced by a run of TeX is the “device independent” (DVI) file that specifies where characters and rules are to appear on printed pages. The form of these files was designed by David R. Fuchs in 1979. Almost any reasonable typesetting device can be driven by a program that takes DVI files as input, and dozens of such DVI-to-whatever programs have been written. Thus, it is possible to print the output of TeX on many different kinds of equipment, using TeX as a device-independent “front end.”

A DVI file is a stream of 8-bit bytes, which may be regarded as a series of commands in a machine-like language. The first byte of each command is the operation code, and this code is followed by zero or more bytes that provide parameters to the command. The parameters themselves may consist of several consecutive bytes; for example, the *set_rule* command has two parameters, each of which is four bytes long. Parameters are usually regarded as nonnegative integers; but four-byte-long parameters, and shorter parameters that denote distances, can be either positive or negative. Such parameters are given in two’s complement notation. For example, a two-byte-long distance parameter has a value between -2^{15} and $2^{15} - 1$. As in TFM files, numbers that occupy more than one byte position appear in BigEndian order.

A DVI file consists of a “preamble,” followed by a sequence of one or more “pages,” followed by a “postamble.” The preamble is simply a *pre* command, with its parameters that define the dimensions used in the file; this must come first. Each “page” consists of a *bop* command, followed by any number of other commands that tell where characters are to be placed on a physical page, followed by an *eop* command. The pages appear in the order that TeX generated them. If we ignore *nop* commands and *fnt_def* commands (which are allowed between any two commands in the file), each *eop* command is immediately followed by a *bop* command, or by a *post* command; in the latter case, there are no more pages in the file, and the remaining bytes form the postamble. Further details about the postamble will be explained later.

Some parameters in DVI commands are “pointers.” These are four-byte quantities that give the location number of some other byte in the file; the first byte is number 0, then comes number 1, and so on. For example, one of the parameters of a *bop* command points to the previous *bop*; this makes it feasible to read the pages in backwards order, in case the results are being directed to a device that stacks its output face up. Suppose the preamble of a DVI file occupies bytes 0 to 99. Now if the first page occupies bytes 100 to 999, say, and if the second page occupies bytes 1000 to 1999, then the *bop* that starts in byte 1000 points to 100 and the *bop* that starts in byte 2000 points to 1000. (The very first *bop*, i.e., the one starting in byte 100, has a pointer of -1 .)

611. The DVI format is intended to be both compact and easily interpreted by a machine. Compactness is achieved by making most of the information implicit instead of explicit. When a DVI-reading program reads the commands for a page, it keeps track of several quantities: (a) The current font f is an integer; this value is changed only by *fnt* and *fnt_num* commands. (b) The current position on the page is given by two numbers called the horizontal and vertical coordinates, h and v . Both coordinates are zero at the upper left corner of the page; moving to the right corresponds to increasing the horizontal coordinate, and moving down corresponds to increasing the vertical coordinate. Thus, the coordinates are essentially Cartesian, except that vertical directions are flipped; the Cartesian version of (h, v) would be $(h, -v)$. (c) The current spacing amounts are given by four numbers w , x , y , and z , where w and x are used for horizontal spacing and where y and z are used for vertical spacing. (d) There is a stack containing (h, v, w, x, y, z) values; the DVI commands *push* and *pop* are used to change the current level of operation. Note that the current font f is not pushed and popped; the stack contains only information about positioning.

The values of h , v , w , x , y , and z are signed integers having up to 32 bits, including the sign. Since they represent physical distances, there is a small unit of measurement such that increasing h by 1 means moving a certain tiny distance to the right. The actual unit of measurement is variable, as explained below; TeX sets things up so that its DVI output is in sp units, i.e., scaled points, in agreement with all the *scaled* dimensions in TeX’s data structures.

612. Here is a list of all the commands that may appear in a DVI file. Each command is specified by its symbolic name (e.g., *bop*), its opcode byte (e.g., 139), and its parameters (if any). The parameters are followed by a bracketed number telling how many bytes they occupy; for example, ‘*p*[4]’ means that parameter *p* is four bytes long.

set_char_0 0. Typeset character number 0 from font *f* such that the reference point of the character is at (h, v) . Then increase *h* by the width of that character. Note that a character may have zero or negative width, so one cannot be sure that *h* will advance after this command; but *h* usually does increase.

set_char_1 through *set_char_127* (opcodes 1 to 127). Do the operations of *set_char_0*; but use the character whose number matches the opcode, instead of character 0.

set1 128 *c*[1]. Same as *set_char_0*, except that character number *c* is typeset. TeX82 uses this command for characters in the range $128 \leq c < 256$.

set2 129 *c*[2]. Same as *set1*, except that *c* is two bytes long, so it is in the range $0 \leq c < 65536$. TeX82 never uses this command, but it should come in handy for extensions of TeX that deal with oriental languages.

set3 130 *c*[3]. Same as *set1*, except that *c* is three bytes long, so it can be as large as $2^{24} - 1$. Not even the Chinese language has this many characters, but this command might prove useful in some yet unforeseen extension.

set4 131 *c*[4]. Same as *set1*, except that *c* is four bytes long. Imagine that.

set_rule 132 *a*[4] *b*[4]. Typeset a solid black rectangle of height *a* and width *b*, with its bottom left corner at (h, v) . Then set $h \leftarrow h + b$. If either $a \leq 0$ or $b \leq 0$, nothing should be typeset. Note that if $b < 0$, the value of *h* will decrease even though nothing else happens. See below for details about how to typeset rules so that consistency with METAFONT is guaranteed.

put1 133 *c*[1]. Typeset character number *c* from font *f* such that the reference point of the character is at (h, v) . (The ‘put’ commands are exactly like the ‘set’ commands, except that they simply put out a character or a rule without moving the reference point afterwards.)

put2 134 *c*[2]. Same as *set2*, except that *h* is not changed.

put3 135 *c*[3]. Same as *set3*, except that *h* is not changed.

put4 136 *c*[4]. Same as *set4*, except that *h* is not changed.

put_rule 137 *a*[4] *b*[4]. Same as *set_rule*, except that *h* is not changed.

nop 138. No operation, do nothing. Any number of *nop*’s may occur between DVI commands, but a *nop* cannot be inserted between a command and its parameters or between two parameters.

bop 139 *c*₀[4] *c*₁[4] ... *c*₉[4] *p*[4]. Beginning of a page: Set $(h, v, w, x, y, z) \leftarrow (0, 0, 0, 0, 0, 0)$ and set the stack empty. Set the current font *f* to an undefined value. The ten *c*_{*i*} parameters hold the values of `\count0` ... `\count9` in TeX at the time `\shipout` was invoked for this page; they can be used to identify pages, if a user wants to print only part of a DVI file. The parameter *p* points to the previous *bop* in the file; the first *bop* has *p* = −1.

eop 140. End of page: Print what you have read since the previous *bop*. At this point the stack should be empty. (The DVI-reading programs that drive most output devices will have kept a buffer of the material that appears on the page that has just ended. This material is largely, but not entirely, in order by *v* coordinate and (for fixed *v*) by *h* coordinate; so it usually needs to be sorted into some order that is appropriate for the device in question.)

push 141. Push the current values of (h, v, w, x, y, z) onto the top of the stack; do not change any of these values. Note that *f* is not pushed.

pop 142. Pop the top six values off of the stack and assign them respectively to (h, v, w, x, y, z) . The number of pops should never exceed the number of pushes, since it would be highly embarrassing if the stack were empty at the time of a *pop* command.

right1 143 *b*[1]. Set $h \leftarrow h + b$, i.e., move right *b* units. The parameter is a signed number in two’s complement notation, $-128 \leq b < 128$; if $b < 0$, the reference point moves left.

right2 144 *b*[2]. Same as *right1*, except that *b* is a two-byte quantity in the range $-32768 \leq b < 32768$.

right3 145 *b*[3]. Same as *right1*, except that *b* is a three-byte quantity in the range $-2^{23} \leq b < 2^{23}$.

right4 146 *b*[4]. Same as *right1*, except that *b* is a four-byte quantity in the range $-2^{31} \leq b < 2^{31}$.

w0 147. Set $h \leftarrow h + w$; i.e., move right *w* units. With luck, this parameterless command will usually suffice, because the same kind of motion will occur several times in succession; the following commands explain how *w* gets particular values.

w1 148 *b*[1]. Set $w \leftarrow b$ and $h \leftarrow h + b$. The value of *b* is a signed quantity in two's complement notation, $-128 \leq b < 128$. This command changes the current *w* spacing and moves right by *b*.

w2 149 *b*[2]. Same as *w1*, but *b* is two bytes long, $-32768 \leq b < 32768$.

w3 150 *b*[3]. Same as *w1*, but *b* is three bytes long, $-2^{23} \leq b < 2^{23}$.

w4 151 *b*[4]. Same as *w1*, but *b* is four bytes long, $-2^{31} \leq b < 2^{31}$.

x0 152. Set $h \leftarrow h + x$; i.e., move right *x* units. The ‘*x*’ commands are like the ‘*w*’ commands except that they involve *x* instead of *w*.

x1 153 *b*[1]. Set $x \leftarrow b$ and $h \leftarrow h + b$. The value of *b* is a signed quantity in two's complement notation, $-128 \leq b < 128$. This command changes the current *x* spacing and moves right by *b*.

x2 154 *b*[2]. Same as *x1*, but *b* is two bytes long, $-32768 \leq b < 32768$.

x3 155 *b*[3]. Same as *x1*, but *b* is three bytes long, $-2^{23} \leq b < 2^{23}$.

x4 156 *b*[4]. Same as *x1*, but *b* is four bytes long, $-2^{31} \leq b < 2^{31}$.

down1 157 *a*[1]. Set $v \leftarrow v + a$, i.e., move down *a* units. The parameter is a signed number in two's complement notation, $-128 \leq a < 128$; if *a* < 0, the reference point moves up.

down2 158 *a*[2]. Same as *down1*, except that *a* is a two-byte quantity in the range $-32768 \leq a < 32768$.

down3 159 *a*[3]. Same as *down1*, except that *a* is a three-byte quantity in the range $-2^{23} \leq a < 2^{23}$.

down4 160 *a*[4]. Same as *down1*, except that *a* is a four-byte quantity in the range $-2^{31} \leq a < 2^{31}$.

y0 161. Set $v \leftarrow v + y$; i.e., move down *y* units. With luck, this parameterless command will usually suffice, because the same kind of motion will occur several times in succession; the following commands explain how *y* gets particular values.

y1 162 *a*[1]. Set $y \leftarrow a$ and $v \leftarrow v + a$. The value of *a* is a signed quantity in two's complement notation, $-128 \leq a < 128$. This command changes the current *y* spacing and moves down by *a*.

y2 163 *a*[2]. Same as *y1*, but *a* is two bytes long, $-32768 \leq a < 32768$.

y3 164 *a*[3]. Same as *y1*, but *a* is three bytes long, $-2^{23} \leq a < 2^{23}$.

y4 165 *a*[4]. Same as *y1*, but *a* is four bytes long, $-2^{31} \leq a < 2^{31}$.

z0 166. Set $v \leftarrow v + z$; i.e., move down *z* units. The ‘*z*’ commands are like the ‘*y*’ commands except that they involve *z* instead of *y*.

z1 167 *a*[1]. Set $z \leftarrow a$ and $v \leftarrow v + a$. The value of *a* is a signed quantity in two's complement notation, $-128 \leq a < 128$. This command changes the current *z* spacing and moves down by *a*.

z2 168 *a*[2]. Same as *z1*, but *a* is two bytes long, $-32768 \leq a < 32768$.

z3 169 *a*[3]. Same as *z1*, but *a* is three bytes long, $-2^{23} \leq a < 2^{23}$.

z4 170 *a*[4]. Same as *z1*, but *a* is four bytes long, $-2^{31} \leq a < 2^{31}$.

fnt_num_0 171. Set $f \leftarrow 0$. Font 0 must previously have been defined by a *fnt_def* instruction, as explained below.

fnt_num_1 through *fnt_num_63* (opcodes 172 to 234). Set $f \leftarrow 1, \dots, f \leftarrow 63$, respectively.

fnt1 235 *k*[1]. Set $f \leftarrow k$. TeX82 uses this command for font numbers in the range $64 \leq k < 256$.

fnt2 236 *k*[2]. Same as *fnt1*, except that *k* is two bytes long, so it is in the range $0 \leq k < 65536$. TeX82 never generates this command, but large font numbers may prove useful for specifications of color or texture, or they may be used for special fonts that have fixed numbers in some external coding scheme.

fnt3 237 $k[3]$. Same as *fnt1*, except that k is three bytes long, so it can be as large as $2^{24} - 1$.

fnt4 238 $k[4]$. Same as *fnt1*, except that k is four bytes long; this is for the really big font numbers (and for the negative ones).

xxx1 239 $k[1]$ $x[k]$. This command is undefined in general; it functions as a $(k + 2)$ -byte *nop* unless special DVI-reading programs are being used. TeX82 generates *xxx1* when a short enough `\special` appears, setting k to the number of bytes being sent. It is recommended that x be a string having the form of a keyword followed by possible parameters relevant to that keyword.

xxx2 240 $k[2]$ $x[k]$. Like *xxx1*, but $0 \leq k < 65536$.

xxx3 241 $k[3]$ $x[k]$. Like *xxx1*, but $0 \leq k < 2^{24}$.

xxx4 242 $k[4]$ $x[k]$. Like *xxx1*, but k can be ridiculously large. TeX82 uses *xxx4* when sending a string of length 256 or more.

fnt_def1 243 $k[1]$ $c[4]$ $s[4]$ $d[4]$ $a[1]$ $l[1]$ $n[a + l]$. Define font k , where $0 \leq k < 256$; font definitions will be explained shortly.

fnt_def2 244 $k[2]$ $c[4]$ $s[4]$ $d[4]$ $a[1]$ $l[1]$ $n[a + l]$. Define font k , where $0 \leq k < 65536$.

fnt_def3 245 $k[3]$ $c[4]$ $s[4]$ $d[4]$ $a[1]$ $l[1]$ $n[a + l]$. Define font k , where $0 \leq k < 2^{24}$.

fnt_def4 246 $k[4]$ $c[4]$ $s[4]$ $d[4]$ $a[1]$ $l[1]$ $n[a + l]$. Define font k , where $-2^{31} \leq k < 2^{31}$.

pre 247 $i[1]$ $num[4]$ $den[4]$ $mag[4]$ $k[1]$ $x[k]$. Beginning of the preamble; this must come at the very beginning of the file. Parameters i , num , den , mag , k , and x are explained below.

post 248. Beginning of the postamble, see below.

post_post 249. Ending of the postamble, see below.

Commands 250–255 are undefined at the present time.

613. `define set_char_0 = 0 {typeset character 0 and move right}`

`define set1 = 128 {typeset a character and move right}`

`define set_rule = 132 {typeset a rule and move right}`

`define put_rule = 137 {typeset a rule}`

`define nop = 138 {no operation}`

`define bop = 139 {beginning of page}`

`define eop = 140 {ending of page}`

`define push = 141 {save the current positions}`

`define pop = 142 {restore previous positions}`

`define right1 = 143 {move right}`

`define w0 = 147 {move right by w }`

`define w1 = 148 {move right and set w }`

`define x0 = 152 {move right by x }`

`define x1 = 153 {move right and set x }`

`define down1 = 157 {move down}`

`define y0 = 161 {move down by y }`

`define y1 = 162 {move down and set y }`

`define z0 = 166 {move down by z }`

`define z1 = 167 {move down and set z }`

`define fnt_num_0 = 171 {set current font to 0}`

`define fnt1 = 235 {set current font}`

`define xxx1 = 239 {extension to DVI primitives}`

`define xxx4 = 242 {potentially long extension to DVI primitives}`

`define fnt_def1 = 243 {define the meaning of a font number}`

`define pre = 247 {preamble}`

`define post = 248 {postamble beginning}`

`define post_post = 249 {postamble ending}`

614. The preamble contains basic information about the file as a whole. As stated above, there are six parameters:

$$i[1] \text{ } num[4] \text{ } den[4] \text{ } mag[4] \text{ } k[1] \text{ } x[k].$$

The i byte identifies DVI format; currently this byte is always set to 2. (The value $i = 3$ is currently used for an extended format that allows a mixture of right-to-left and left-to-right typesetting. Some day we will set $i = 4$, when DVI format makes another incompatible change—perhaps in the year 2048.)

The next two parameters, num and den , are positive integers that define the units of measurement; they are the numerator and denominator of a fraction by which all dimensions in the DVI file could be multiplied in order to get lengths in units of 10^{-7} meters. Since $7227\text{pt} = 254\text{cm}$, and since TeX works with scaled points where there are 2^{16} sp in a point, TeX sets $num/den = (254 \cdot 10^5)/(7227 \cdot 2^{16}) = 25400000/473628672$.

The mag parameter is what TeX calls `\mag`, i.e., 1000 times the desired magnification. The actual fraction by which dimensions are multiplied is therefore $mag \cdot num/1000den$. Note that if a TeX source document does not call for any ‘true’ dimensions, and if you change it only by specifying a different `\mag` setting, the DVI file that TeX creates will be completely unchanged except for the value of mag in the preamble and postamble. (Fancy DVI-reading programs allow users to override the mag setting when a DVI file is being printed.)

Finally, k and x allow the DVI writer to include a comment, which is not interpreted further. The length of comment x is k , where $0 \leq k < 256$.

define $id_byte = 2$ { identifies the kind of DVI files described here }

615. Font definitions for a given font number k contain further parameters

$$c[4] \text{ } s[4] \text{ } d[4] \text{ } a[1] \text{ } l[1] \text{ } n[a+l].$$

The four-byte value c is the check sum that TeX found in the TFM file for this font; c should match the check sum of the font found by programs that read this DVI file.

Parameter s contains a fixed-point scale factor that is applied to the character widths in font k ; font dimensions in TFM files and other font files are relative to this quantity, which is called the “at size” elsewhere in this documentation. The value of s is always positive and less than 2^{27} . It is given in the same units as the other DVI dimensions, i.e., in sp when TeX82 has made the file. Parameter d is similar to s ; it is the “design size,” and (like s) it is given in DVI units. Thus, font k is to be used at $mag \cdot s/1000d$ times its normal size.

The remaining part of a font definition gives the external name of the font, which is an ASCII string of length $a + l$. The number a is the length of the “area” or directory, and l is the length of the font name itself; the standard local system font area is supposed to be used when $a = 0$. The n field contains the area in its first a bytes.

Font definitions must appear before the first use of a particular font number. Once font k is defined, it must not be defined again; however, we shall see below that font definitions appear in the postamble as well as in the pages, so in this sense each font number is defined exactly twice, if at all. Like `nop` commands, font definitions can appear before the first `bop`, or between an `eop` and a `bop`.

616. Sometimes it is desirable to make horizontal or vertical rules line up precisely with certain features in characters of a font. It is possible to guarantee the correct matching between DVI output and the characters generated by METAFONT by adhering to the following principles: (1) The METAFONT characters should be positioned so that a bottom edge or left edge that is supposed to line up with the bottom or left edge of a rule appears at the reference point, i.e., in row 0 and column 0 of the METAFONT raster. This ensures that the position of the rule will not be rounded differently when the pixel size is not a perfect multiple of the units of measurement in the DVI file. (2) A typeset rule of height $a > 0$ and width $b > 0$ should be equivalent to a METAFONT-generated character having black pixels in precisely those raster positions whose METAFONT coordinates satisfy $0 \leq x < ab$ and $0 \leq y < \alpha a$, where α is the number of pixels per DVI unit.

617. The last page in a DVI file is followed by ‘*post*’; this command introduces the postamble, which summarizes important facts that TeX has accumulated about the file, making it possible to print subsets of the data with reasonable efficiency. The postamble has the form

```

post p[4] num[4] den[4] mag[4] l[4] u[4] s[2] t[2]
< font definitions >
post_post q[4] i[1] 223's[≥4]

```

Here *p* is a pointer to the final *bop* in the file. The next three parameters, *num*, *den*, and *mag*, are duplicates of the quantities that appeared in the preamble.

Parameters *l* and *u* give respectively the height-plus-depth of the tallest page and the width of the widest page, in the same units as other dimensions of the file. These numbers might be used by a DVI-reading program to position individual “pages” on large sheets of film or paper; however, the standard convention for output on normal size paper is to position each page so that the upper left-hand corner is exactly one inch from the left and the top. Experience has shown that it is unwise to design DVI-to-printer software that attempts cleverly to center the output; a fixed position of the upper left corner is easiest for users to understand and to work with. Therefore *l* and *u* are often ignored.

Parameter *s* is the maximum stack depth (i.e., the largest excess of *push* commands over *pop* commands) needed to process this file. Then comes *t*, the total number of pages (*bop* commands) present.

The postamble continues with font definitions, which are any number of *fnt_def* commands as described above, possibly interspersed with *nop* commands. Each font number that is used in the DVI file must be defined exactly twice: Once before it is first selected by a *fnt* command, and once in the postamble.

618. The last part of the postamble, following the *post_post* byte that signifies the end of the font definitions, contains *q*, a pointer to the *post* command that started the postamble. An identification byte, *i*, comes next; this currently equals 2, as in the preamble.

The *i* byte is followed by four or more bytes that are all equal to the decimal number 223 (i.e., ‘337 in octal). TeX puts out four to seven of these trailing bytes, until the total length of the file is a multiple of four bytes, since this works out best on machines that pack four bytes per word; but any number of 223’s is allowed, as long as there are at least four of them. In effect, 223 is a sort of signature that is added at the very end.

This curious way to finish off a DVI file makes it feasible for DVI-reading programs to find the postamble first, on most computers, even though TeX wants to write the postamble last. Most operating systems permit random access to individual words or bytes of a file, so the DVI reader can start at the end and skip backwards over the 223’s until finding the identification byte. Then it can back up four bytes, read *q*, and move to byte *q* of the file. This byte should, of course, contain the value 248 (*post*); now the postamble can be read, so the DVI reader can discover all the information needed for typesetting the pages. Note that it is also possible to skip through the DVI file at reasonably high speed to locate a particular page, if that proves desirable. This saves a lot of time, since DVI files used in production jobs tend to be large.

Unfortunately, however, standard Pascal does not include the ability to access a random position in a file, or even to determine the length of a file. Almost all systems nowadays provide the necessary capabilities, so DVI format has been designed to work most efficiently with modern operating systems. But if DVI files have to be processed under the restrictions of standard Pascal, one can simply read them from front to back, since the necessary header information is present in the preamble and in the font definitions. (The *l* and *u* and *s* and *t* parameters, which appear only in the postamble, are “frills” that are handy but not absolutely necessary.)

619. Shipping pages out. After considering TeX’s eyes and stomach, we come now to the bowels.

The *ship_out* procedure is given a pointer to a box; its mission is to describe that box in DVI form, outputting a “page” to *dvi_file*. The DVI coordinates $(h, v) = (0, 0)$ should correspond to the upper left corner of the box being shipped.

Since boxes can be inside of boxes inside of boxes, the main work of *ship_out* is done by two mutually recursive routines, *hlist_out* and *vlist_out*, which traverse the hlists and vlists inside of horizontal and vertical boxes.

As individual pages are being processed, we need to accumulate information about the entire set of pages, since such statistics must be reported in the postamble. The global variables *total_pages*, *max_v*, *max_h*, *max_push*, and *last_bop* are used to record this information.

The variable *doing_leaders* is *true* while leaders are being output. The variable *dead_cycles* contains the number of times an output routine has been initiated since the last *ship_out*.

A few additional global variables are also defined here for use in *vlist_out* and *hlist_out*. They could have been local variables, but that would waste stack space when boxes are deeply nested, since the values of these variables are not needed during recursive calls.

⟨Global variables 13⟩ +≡

total_pages: integer; { the number of pages that have been shipped out }
max_v: scaled; { maximum height-plus-depth of pages shipped so far }
max_h: scaled; { maximum width of pages shipped so far }
max_push: integer; { deepest nesting of *push* commands encountered so far }
last_bop: integer; { location of previous *bop* in the DVI output }
dead_cycles: integer; { recent outputs that didn’t ship anything out }
doing_leaders: boolean; { are we inside a leader box? }
c, f: quarterword; { character and font in current *char_node* }
rule_ht, rule_dp, rule_wd: scaled; { size of current rule being output }
g: pointer; { current glue specification }
lq, lr: integer; { quantities used in calculations for leaders }

620. ⟨Set initial values of key variables 21⟩ +≡

total_pages ← 0; *max_v* ← 0; *max_h* ← 0; *max_push* ← 0; *last_bop* ← −1; *doing_leaders* ← *false*;
dead_cycles ← 0; *cur_s* ← −1;

621. The DVI bytes are output to a buffer instead of being written directly to the output file. This makes it possible to reduce the overhead of subroutine calls, thereby measurably speeding up the computation, since output of DVI bytes is part of TeX’s inner loop. And it has another advantage as well, since we can change instructions in the buffer in order to make the output more compact. For example, a ‘*down2*’ command can be changed to a ‘*y2*’, thereby making a subsequent ‘*y0*’ command possible, saving two bytes.

The output buffer is divided into two parts of equal size; the bytes found in *dvi_buf*[0 .. *half_buf* − 1] constitute the first half, and those in *dvi_buf*[*half_buf* .. *dvi_buf_size* − 1] constitute the second. The global variable *dvi_ptr* points to the position that will receive the next output byte. When *dvi_ptr* reaches *dvi_limit*, which is always equal to one of the two values *half_buf* or *dvi_buf_size*, the half buffer that is about to be invaded next is sent to the output and *dvi_limit* is changed to its other value. Thus, there is always at least a half buffer’s worth of information present, except at the very beginning of the job.

Bytes of the DVI file are numbered sequentially starting with 0; the next byte to be generated will be number *dvi_offset* + *dvi_ptr*. A byte is present in the buffer only if its number is ≥ *dvi_gone*.

⟨Types in the outer block 18⟩ +≡

dvi_index = 0 .. *dvi_buf_size*; { an index into the output buffer }

622. Some systems may find it more efficient to make *dvi_buf* a **packed** array, since output of four bytes at once may be facilitated.

```

⟨Global variables 13⟩ +≡
dvi_buf: array [dvi_index] of eight_bits; { buffer for DVI output }
half_buf: dvi_index; { half of dvi_buf_size }
dvi_limit: dvi_index; { end of the current half buffer }
dvi_ptr: dvi_index; { the next available buffer address }
dvi_offset: integer; { dvi_buf_size times the number of times the output buffer has been fully emptied }
dvi_gone: integer; { the number of bytes already output to dvi_file }

```

623. Initially the buffer is all in one piece; we will output half of it only after it first fills up.

```

⟨Set initial values of key variables 21⟩ +≡
half_buf ← dvi_buf_size div 2; dvi_limit ← dvi_buf_size; dvi_ptr ← 0; dvi_offset ← 0; dvi_gone ← 0;

```

624. The actual output of *dvi_buf*[*a* .. *b*] to *dvi_file* is performed by calling *write_dvi*(*a*, *b*). For best results, this procedure should be optimized to run as fast as possible on each particular system, since it is part of TeX's inner loop. It is safe to assume that *a* and *b* + 1 will both be multiples of 4 when *write_dvi*(*a*, *b*) is called; therefore it is possible on many machines to use efficient methods to pack four bytes per word and to output an array of words with one system call.

```

procedure write_dvi(a, b : dvi_index);
  var k: dvi_index;
  begin for k ← a to b do write(dvi_file, dvi_buf[k]);
  end;

```

625. To put a byte in the buffer without paying the cost of invoking a procedure each time, we use the macro *dvi_out*.

```

define dvi_out(#) ≡ begin dvi_buf[dvi_ptr] ← #; incr(dvi_ptr);
  if dvi_ptr = dvi_limit then dvi_swap;
  end
procedure dvi_swap; { outputs half of the buffer }
  begin if dvi_limit = dvi_buf_size then
    begin write_dvi(0, half_buf - 1); dvi_limit ← half_buf; dvi_offset ← dvi_offset + dvi_buf_size;
    dvi_ptr ← 0;
    end
  else begin write_dvi(half_buf, dvi_buf_size - 1); dvi_limit ← dvi_buf_size;
  end;
  dvi_gone ← dvi_gone + half_buf;
end;

```

626. Here is how we clean out the buffer when TeX is all through; *dvi_ptr* will be a multiple of 4.

```

⟨Empty the last bytes out of dvi_buf 626⟩ ≡
  if dvi_limit = half_buf then write_dvi(half_buf, dvi_buf_size - 1);
  if dvi_ptr > 0 then write_dvi(0, dvi_ptr - 1)

```

This code is used in section 670.

627. The *dvi_four* procedure outputs four bytes in two’s complement notation, without risking arithmetic overflow.

```

procedure dvi_four(x : integer);
  begin if x ≥ 0 then dvi_out(x div '100000000)
  else begin x ← x + '10000000000; x ← x + '10000000000; dvi_out((x div '100000000) + 128);
    end;
  x ← x mod '100000000; dvi_out(x div '200000); x ← x mod '200000; dvi_out(x div '400);
  dvi_out(x mod '400);
end;

```

628. A mild optimization of the output is performed by the *dvi_pop* routine, which issues a *pop* unless it is possible to cancel a ‘*push pop*’ pair. The parameter to *dvi_pop* is the byte address following the old *push* that matches the new *pop*.

```

procedure dvi_pop(l : integer);
  begin if (l = dvi_offset + dvi_ptr) ∧ (dvi_ptr > 0) then decr(dvi_ptr)
  else dvi_out(pop);
end;

```

629. Here’s a procedure that outputs a font definition. Since TeX82 uses at most 256 different fonts per job, *font_def1* is always used as the command code.

```

procedure dvi_font_def(f : internal_font_number);
  var k: pool_pointer; { index into str_pool }
  begin dvi_out(font_def1); dvi_out(f − font_base − 1);
  dvi_out(qo(font_check[f].b0)); dvi_out(qo(font_check[f].b1)); dvi_out(qo(font_check[f].b2));
  dvi_out(qo(font_check[f].b3));
  dvi_four(font_size[f]); dvi_four(font_dsize[f]);
  dvi_out(length(font_area[f])); dvi_out(length(font_name[f]));
  ⟨ Output the font name whose internal number is f 630 ⟩;
end;

```

630. ⟨ Output the font name whose internal number is *f* 630 ⟩ ≡

```

for k ← str_start[font_area[f]] to str_start[font_area[f] + 1] − 1 do dvi_out(so(str_pool[k]));
for k ← str_start[font_name[f]] to str_start[font_name[f] + 1] − 1 do dvi_out(so(str_pool[k]))

```

This code is used in section 629.

631. Versions of T_EX intended for small computers might well choose to omit the ideas in the next few parts of this program, since it is not really necessary to optimize the DVI code by making use of the $w\theta$, $x\theta$, $y\theta$, and $z\theta$ commands. Furthermore, the algorithm that we are about to describe does not pretend to give an optimum reduction in the length of the DVI code; after all, speed is more important than compactness. But the method is surprisingly effective, and it takes comparatively little time.

We can best understand the basic idea by first considering a simpler problem that has the same essential characteristics. Given a sequence of digits, say 3 1 4 1 5 9 2 6 5 3 5 8 9, we want to assign subscripts d , y , or z to each digit so as to maximize the number of “ y -hits” and “ z -hits”; a y -hit is an instance of two appearances of the same digit with the subscript y , where no y ’s intervene between the two appearances, and a z -hit is defined similarly. For example, the sequence above could be decorated with subscripts as follows:

$$3_z 1_y 4_d 1_y 5_y 9_d 2_d 6_d 5_y 3_z 5_y 8_d 9_d.$$

There are three y -hits ($1_y \dots 1_y$ and $5_y \dots 5_y \dots 5_y$) and one z -hit ($3_z \dots 3_z$); there are no d -hits, since the two appearances of 9_d have d ’s between them, but we don’t count d -hits so it doesn’t matter how many there are. These subscripts are analogous to the DVI commands called *down*, y , and z , and the digits are analogous to different amounts of vertical motion; a y -hit or z -hit corresponds to the opportunity to use the one-byte commands $y\theta$ or $z\theta$ in a DVI file.

T_EX’s method of assigning subscripts works like this: Append a new digit, say δ , to the right of the sequence. Now look back through the sequence until one of the following things happens: (a) You see δ_y or δ_z , and this was the first time you encountered a y or z subscript, respectively. Then assign y or z to the new δ ; you have scored a hit. (b) You see δ_d , and no y subscripts have been encountered so far during this search. Then change the previous δ_d to δ_y (this corresponds to changing a command in the output buffer), and assign y to the new δ ; it’s another hit. (c) You see δ_d , and a y subscript has been seen but not a z . Change the previous δ_d to δ_z and assign z to the new δ . (d) You encounter both y and z subscripts before encountering a suitable δ , or you scan all the way to the front of the sequence. Assign d to the new δ ; this assignment may be changed later.

The subscripts $3_z 1_y 4_d \dots$ in the example above were, in fact, produced by this procedure, as the reader can verify. (Go ahead and try it.)

632. In order to implement such an idea, T_EX maintains a stack of pointers to the *down*, y , and z commands that have been generated for the current page. And there is a similar stack for *right*, w , and x commands. These stacks are called the down stack and right stack, and their top elements are maintained in the variables *down_ptr* and *right_ptr*.

Each entry in these stacks contains four fields: The *width* field is the amount of motion down or to the right; the *location* field is the byte number of the DVI command in question (including the appropriate *dvi_offset*); the *link* field points to the next item below this one on the stack; and the *info* field encodes the options for possible change in the DVI command.

```
define movement_node_size = 3 { number of words per entry in the down and right stacks }
define location(#)  $\equiv$  mem[# + 2].int { DVI byte number for a movement command }
```

```
<Global variables 13> +=
```

```
down_ptr, right_ptr: pointer; { heads of the down and right stacks }
```

633. <Set initial values of key variables 21> +=

```
down_ptr  $\leftarrow$  null; right_ptr  $\leftarrow$  null;
```

634. Here is a subroutine that produces a DVI command for some specified downward or rightward motion. It has two parameters: w is the amount of motion, and o is either *down1* or *right1*. We use the fact that the command codes have convenient arithmetic properties: $y1 - \text{down1} = w1 - \text{right1}$ and $z1 - \text{down1} = x1 - \text{right1}$.

```

procedure movement( $w$  : scaled;  $o$  : eight_bits);
  label exit, found, not_found, 2, 1;
  var mstate: small_number; { have we seen a  $y$  or  $z$ ? }
       $p, q$ : pointer; { current and top nodes on the stack }
       $k$ : integer; { index into dvi_buf, modulo dvi_buf_size }
  begin  $q \leftarrow \text{get\_node}(\text{movement\_node\_size})$ ; { new node for the top of the stack }
      width( $q$ )  $\leftarrow w$ ; location( $q$ )  $\leftarrow \text{dvi\_offset} + \text{dvi\_ptr}$ ;
  if  $o = \text{down1}$  then
    begin link( $q$ )  $\leftarrow \text{down\_ptr}$ ; down_ptr  $\leftarrow q$ ;
    end
  else begin link( $q$ )  $\leftarrow \text{right\_ptr}$ ; right_ptr  $\leftarrow q$ ;
  end;
  < Look at the other stack entries until deciding what sort of DVI command to generate; goto found if
    node  $p$  is a “hit” 638 >;
  < Generate a down or right command for  $w$  and return 637 >;
found: < Generate a  $y0$  or  $z0$  command in order to reuse a previous appearance of  $w$  636 >;
exit: end;

```

635. The *info* fields in the entries of the down stack or the right stack have six possible settings: y_here or z_here mean that the DVI command refers to y or z , respectively (or to w or x , in the case of horizontal motion); yz_OK means that the DVI command is *down* (or *right*) but can be changed to either y or z (or to either w or x); y_OK means that it is *down* and can be changed to y but not z ; z_OK is similar; and *d_fixed* means it must stay *down*.

The four settings yz_OK , y_OK , z_OK , *d_fixed* would not need to be distinguished from each other if we were simply solving the digit-subscripting problem mentioned above. But in TeX’s case there is a complication because of the nested structure of *push* and *pop* commands. Suppose we add parentheses to the digit-subscripting problem, redefining hits so that $\delta_y \dots \delta_y$ is a hit if all y ’s between the δ ’s are enclosed in properly nested parentheses, and if the parenthesis level of the right-hand δ_y is deeper than or equal to that of the left-hand one. Thus, ‘(’ and ‘)’ correspond to ‘*push*’ and ‘*pop*’. Now if we want to assign a subscript to the final 1 in the sequence

$$2_y 7_d 1_d (8_z 2_y 8_z) 1$$

we cannot change the previous 1_d to 1_y , since that would invalidate the $2_y \dots 2_y$ hit. But we can change it to 1_z , scoring a hit since the intervening 8_z ’s are enclosed in parentheses.

The program below removes movement nodes that are introduced after a *push*, before it outputs the corresponding *pop*.

```

define  $y\_here = 1$  { info when the movement entry points to a  $y$  command }
define  $z\_here = 2$  { info when the movement entry points to a  $z$  command }
define  $yz\_OK = 3$  { info corresponding to an unconstrained down command }
define  $y\_OK = 4$  { info corresponding to a down that can’t become a  $z$  }
define  $z\_OK = 5$  { info corresponding to a down that can’t become a  $y$  }
define  $d\_fixed = 6$  { info corresponding to a down that can’t change }

```

636. When the *movement* procedure gets to the label *found*, the value of *info(p)* will be either *y_here* or *z_here*. If it is, say, *y_here*, the procedure generates a *y0* command (or a *w0* command), and marks all *info* fields between *q* and *p* so that *y* is not OK in that range.

```

⟨Generate a y0 or z0 command in order to reuse a previous appearance of w 636⟩ ≡
  info(q) ← info(p);
  if info(q) = y_here then
    begin dvi_out(o + y0 - down1); { y0 or w0 }
    while link(q) ≠ p do
      begin q ← link(q);
      case info(q) of
        yz_OK: info(q) ← z_OK;
        y_OK: info(q) ← d_fixed;
        othercases do_nothing
      endcases;
    end;
  end
else begin dvi_out(o + z0 - down1); { z0 or x0 }
  while link(q) ≠ p do
    begin q ← link(q);
    case info(q) of
      yz_OK: info(q) ← y_OK;
      z_OK: info(q) ← d_fixed;
      othercases do_nothing
    endcases;
  end;
end

```

This code is used in section 634.

637. ⟨Generate a *down* or *right* command for *w* and **return** 637⟩ ≡

```

  info(q) ← yz_OK;
  if abs(w) ≥ '40000000 then
    begin dvi_out(o + 3); { down4 or right4 }
    dvi_four(w); return;
  end;
  if abs(w) ≥ '100000 then
    begin dvi_out(o + 2); { down3 or right3 }
    if w < 0 then w ← w + '100000000;
    dvi_out(w div '200000); w ← w mod '200000; goto 2;
  end;
  if abs(w) ≥ '200 then
    begin dvi_out(o + 1); { down2 or right2 }
    if w < 0 then w ← w + '200000;
    goto 2;
  end;
  dvi_out(o); { down1 or right1 }
  if w < 0 then w ← w + '400;
  goto 1;
2: dvi_out(w div '400);
1: dvi_out(w mod '400); return

```

This code is used in section 634.

638. As we search through the stack, we are in one of three states, *y_seen*, *z_seen*, or *none_seen*, depending on whether we have encountered *y_here* or *z_here* nodes. These states are encoded as multiples of 6, so that they can be added to the *info* fields for quick decision-making.

```

define none_seen = 0 { no y_here or z_here nodes have been encountered yet }
define y_seen = 6 { we have seen y_here but not z_here }
define z_seen = 12 { we have seen z_here but not y_here }

⟨ Look at the other stack entries until deciding what sort of DVI command to generate; goto found if node
  p is a “hit” 638 ⟩ ≡
  p ← link(q); mstate ← none_seen;
  while p ≠ null do
    begin if width(p) = w then ⟨ Consider a node with matching width; goto found if it’s a hit 639 ⟩
    else case mstate + info(p) of
      none_seen + y_here: mstate ← y_seen;
      none_seen + z_here: mstate ← z_seen;
      y_seen + z_here, z_seen + y_here: goto not_found;
      othercases do_nothing
    endcases;
    p ← link(p);
  end;
not_found:

```

This code is used in section 634.

639. We might find a valid hit in a *y* or *z* byte that is already gone from the buffer. But we can’t change bytes that are gone forever; “the moving finger writes, . . .”

```

⟨ Consider a node with matching width; goto found if it’s a hit 639 ⟩ ≡
case mstate + info(p) of
  none_seen + yz_OK, none_seen + y_OK, z_seen + yz_OK, z_seen + y_OK:
    if location(p) < dvi_gone then goto not_found
    else ⟨ Change buffered instruction to y or w and goto found 640 ⟩;
  none_seen + z_OK, y_seen + yz_OK, y_seen + z_OK:
    if location(p) < dvi_gone then goto not_found
    else ⟨ Change buffered instruction to z or x and goto found 641 ⟩;
  none_seen + y_here, none_seen + z_here, y_seen + z_here, z_seen + y_here: goto found;
othercases do_nothing
endcases

```

This code is used in section 638.

```

640. ⟨ Change buffered instruction to y or w and goto found 640 ⟩ ≡
  begin k ← location(p) − dvi_offset;
  if k < 0 then k ← k + dvi_buf_size;
  dvi_buf[k] ← dvi_buf[k] + y1 − down1; info(p) ← y_here; goto found;
end

```

This code is used in section 639.

```

641. ⟨ Change buffered instruction to z or x and goto found 641 ⟩ ≡
  begin k ← location(p) − dvi_offset;
  if k < 0 then k ← k + dvi_buf_size;
  dvi_buf[k] ← dvi_buf[k] + z1 − down1; info(p) ← z_here; goto found;
end

```

This code is used in section 639.

642. In case you are wondering when all the movement nodes are removed from T_EX's memory, the answer is that they are recycled just before *hlist_out* and *vlist_out* finish outputting a box. This restores the down and right stacks to the state they were in before the box was output, except that some *info*'s may have become more restrictive.

```

procedure prune_movements(l : integer); { delete movement nodes with location  $\geq l$  }
  label done, exit;
  var p: pointer; { node being deleted }
  begin while down_ptr  $\neq$  null do
    begin if location(down_ptr)  $< l$  then goto done;
    p  $\leftarrow$  down_ptr; down_ptr  $\leftarrow$  link(p); free_node(p, movement_node_size);
    end;
  done: while right_ptr  $\neq$  null do
    begin if location(right_ptr)  $< l$  then return;
    p  $\leftarrow$  right_ptr; right_ptr  $\leftarrow$  link(p); free_node(p, movement_node_size);
    end;
  exit: end;

```


643. The actual distances by which we want to move might be computed as the sum of several separate movements. For example, there might be several glue nodes in succession, or we might want to move right by the width of some box plus some amount of glue. More importantly, the baselineskip distances are computed in terms of glue together with the depth and height of adjacent boxes, and we want the DVI file to lump these three quantities together into a single motion.

Therefore, TeX maintains two pairs of global variables: *dvi_h* and *dvi_v* are the *h* and *v* coordinates corresponding to the commands actually output to the DVI file, while *cur_h* and *cur_v* are the coordinates corresponding to the current state of the output routines. Coordinate changes will accumulate in *cur_h* and *cur_v* without being reflected in the output, until such a change becomes necessary or desirable; we can call the *movement* procedure whenever we want to make *dvi_h* = *cur_h* or *dvi_v* = *cur_v*.

The current font reflected in the DVI output is called *dvi_f*; there is no need for a ‘*cur_f*’ variable.

The depth of nesting of *hlist_out* and *vlist_out* is called *cur_s*; this is essentially the depth of *push* commands in the DVI output.

For mixed direction text (TeX--X_qT) the current text direction is called *cur_dir*. As the box being shipped out will never be used again and soon be recycled, we can simply reverse any R-text (i.e., right-to-left) segments of *hlist* nodes as well as complete *hlist* nodes embedded in such segments. Moreover this can be done iteratively rather than recursively. There are, however, two complications related to leaders that require some additional bookkeeping: (1) One and the same *hlist* node might be used more than once (but never inside both L- and R-text); and (2) leader boxes inside *hlists* must be aligned with respect to the left edge of the original *hlist*.

A math node is changed into a kern node whenever the text direction remains the same, it is replaced by an *edge_node* if the text direction changes; the subtype of an *hlist_node* inside R-text is changed to *reversed* once its *hlist* has been reversed.

```

define reversed = 1 { subtype for an hlist_node whose hlist has been reversed }
define dlist = 2 { subtype for an hlist_node from display math mode }
define box_lr(#) ≡ (qo(subtype(#))) { direction mode of a box }
define set_box_lr(#) ≡ subtype(#) ← set_box_lr_end
define set_box_lr_end(#) ≡ qi(#)
define left_to_right = 0
define right_to_left = 1
define reflected ≡ 1 - cur_dir { the opposite of cur_dir }
define synch_h ≡
  if cur_h ≠ dvi_h then
    begin movement(cur_h - dvi_h, right1); dvi_h ← cur_h;
    end
define synch_v ≡
  if cur_v ≠ dvi_v then
    begin movement(cur_v - dvi_v, down1); dvi_v ← cur_v;
    end

⟨Global variables 13⟩ +=
dvi_h, dvi_v: scaled; { a DVI reader program thinks we are here }
cur_h, cur_v: scaled; { TeX thinks we are here }
dvi_f: internal_font_number; { the current font }
cur_s: integer; { current depth of output box nesting, initially -1 }

```

644. \langle Calculate DVI page dimensions and margins 644 $\rangle \equiv$
 $cur_h_offset \leftarrow h_offset; cur_v_offset \leftarrow v_offset;$
if $pdf_page_width \neq 0$ **then** $cur_page_width \leftarrow pdf_page_width$
else $cur_page_width \leftarrow width(p) + 2 * cur_h_offset + 2 * 4736286;$
 $\{ 4736286 = 1in, \text{ the funny DVI origin offset } \}$
if $pdf_page_height \neq 0$ **then** $cur_page_height \leftarrow pdf_page_height$
else $cur_page_height \leftarrow height(p) + depth(p) + 2 * cur_v_offset + 2 * 4736286$
 $\{ 4736286 = 1in, \text{ the funny DVI origin offset } \}$

This code is used in section 645.

645. \langle Initialize variables as *ship_out* begins 645 $\rangle \equiv$
 $dvi_h \leftarrow 0; dvi_v \leftarrow 0; cur_h \leftarrow h_offset; dvi_f \leftarrow null_font;$
 \langle Calculate DVI page dimensions and margins 644 $\rangle;$
 $ensure_dvi_open;$
if $total_pages = 0$ **then**
 $begin$ $dvi_out(pre); dvi_out(id_byte);$ { output the preamble }
 $dvi_four(25400000); dvi_four(473628672);$ { conversion ratio for sp }
 $prepare_mag; dvi_four(mag);$ { magnification factor is frozen }
 $old_setting \leftarrow selector; selector \leftarrow new_string; print("_TeX_output_"); print_int(year);$
 $print_char("."); print_two(month); print_char("."); print_two(day); print_char(":");$
 $print_two(time \mathbf{div} 60); print_two(time \mathbf{mod} 60); selector \leftarrow old_setting; dvi_out(cur_length);$
for $s \leftarrow str_start[str_ptr]$ **to** $pool_ptr - 1$ **do** $dvi_out(so(str_pool[s]));$
 $pool_ptr \leftarrow str_start[str_ptr];$ { flush the current string }
end

This code is used in section 668.

646. When *hlist_out* is called, its duty is to output the box represented by the *hlist_node* pointed to by *temp_ptr*. The reference point of that box has coordinates (*cur_h*, *cur_v*).

Similarly, when *vlist_out* is called, its duty is to output the box represented by the *vlist_node* pointed to by *temp_ptr*. The reference point of that box has coordinates (*cur_h*, *cur_v*).

procedure *vlist_out*; *forward*; { *hlist_out* and *vlist_out* are mutually recursive }

647. The recursive procedures *hlist_out* and *vlist_out* each have local variables *save_h* and *save_v* to hold the values of *dvi_h* and *dvi_v* just before entering a new level of recursion. In effect, the values of *save_h* and *save_v* on TeX's run-time stack correspond to the values of *h* and *v* that a DVI-reading program will push onto its coordinate stack.

```

define move_past = 13 { go to this label when advancing past glue or a rule }
define fin_rule = 14 { go to this label to finish processing a rule }
define next_p = 15 { go to this label when finished with node p }

⟨ Declare procedures needed in hlist_out, vlist_out 1612 ⟩
procedure hlist_out; { output an hlist_node box }
  label reswitch, move_past, fin_rule, next_p;
  var base_line: scaled; { the baseline coordinate for this box }
    left_edge: scaled; { the left coordinate for this box }
    save_h, save_v: scaled; { what dvi_h and dvi_v should pop to }
    this_box: pointer; { pointer to containing box }
    g_order: glue_ord; { applicable order of infinity for glue }
    g_sign: normal .. shrinking; { selects type of glue }
    p: pointer; { current position in the hlist }
    save_loc: integer; { DVI byte location upon entry }
    leader_box: pointer; { the leader box being replicated }
    leader_wd: scaled; { width of leader box being replicated }
    lx: scaled; { extra space between leader boxes }
    outer_doing_leaders: boolean; { were we doing leaders? }
    edge: scaled; { right edge of sub-box or leader space }
    prev_p: pointer; { one step behind p }
    glue_temp: real; { glue value before rounding }
    cur_glue: real; { glue seen so far }
    cur_g: scaled; { rounded equivalent of cur_glue times the glue ratio }
  begin cur_g ← 0; cur_glue ← float_constant(0); this_box ← temp_ptr; g_order ← glue_order(this_box);
  g_sign ← glue_sign(this_box); p ← list_ptr(this_box); incr(cur_s);
  if cur_s > 0 then dvi_out(push);
  if cur_s > max_push then max_push ← cur_s;
  save_loc ← dvi_offset + dvi_ptr; base_line ← cur_v; prev_p ← this_box + list_offset;
  ⟨ Initialize hlist_out for mixed direction typesetting 1711 ⟩;
  left_edge ← cur_h;
  while p ≠ null do ⟨ Output node p for hlist_out and move to the next node, maintaining the condition
    cur_v = base_line 648 ⟩;
  ⟨ Finish hlist_out for mixed direction typesetting 1712 ⟩;
  prune_movements(save_loc);
  if cur_s > 0 then dvi_pop(save_loc);
  decr(cur_s);
end;

```

648. We ought to give special care to the efficiency of one part of *hlist_out*, since it belongs to T_EX's inner loop. When a *char_node* is encountered, we save a little time by processing several nodes in succession until reaching a non-*char_node*. The program uses the fact that *set_char_0* = 0.

⟨Output node *p* for *hlist_out* and move to the next node, maintaining the condition *cur_v* = *base_line* 648⟩ ≡
reswitch: **if** *is_char_node*(*p*) **then**

```

  begin synch_h; synch_v;
  repeat f ← font(p); c ← character(p);
    if f ≠ dvi_f then ⟨Change font dvi_f to f 649⟩;
    if c ≥ qi(128) then dvi_out(set1);
    dvi_out(qo(c));
    cur_h ← cur_h + char_width(f)(char_info(f)(c)); prev_p ← link(prev_p);
    { N.B.: not prev_p ← p, p might be lig_trick }
    p ← link(p);
  until ¬is_char_node(p);
  dvi_h ← cur_h;
end

```

else ⟨Output the non-*char_node* *p* for *hlist_out* and move to the next node 650⟩

This code is used in section 647.

649. ⟨Change font *dvi_f* to *f* 649⟩ ≡

```

begin if ¬font_used[f] then
  begin dvi_font_def(f); font_used[f] ← true;
  end;
if f ≤ 64 + font_base then dvi_out(f − font_base − 1 + fnt_num_0)
else begin dvi_out(fnt1); dvi_out(f − font_base − 1);
  end;
  dvi_f ← f;
end

```

This code is used in section 648.

650. ⟨Output the non-*char_node* *p* for *hlist_out* and move to the next node 650⟩ ≡

```

begin case type(p) of
  hlist_node, vlist_node: ⟨Output a box in an hlist 651⟩;
  rule_node: begin rule_ht ← height(p); rule_dp ← depth(p); rule_wd ← width(p); goto fin_rule;
  end;
  whatsit_node: ⟨Output the whatsit node p in an hlist 1611⟩;
  glue_node: ⟨Move right or output leaders 653⟩;
  margin_kern_node, kern_node: cur_h ← cur_h + width(p);
  math_node: ⟨Handle a math node in hlist_out 1713⟩;
  ligature_node: ⟨Make node p look like a char_node and goto reswitch 824⟩;
  ⟨Cases of hlist_out that arise in mixed direction text only 1717⟩
othercases do_nothing
endcases;
goto next_p;
fin_rule: ⟨Output a rule in an hlist 652⟩;
move_past: cur_h ← cur_h + rule_wd;
next_p: prev_p ← p; p ← link(p);
end

```

This code is used in section 648.

651. \langle Output a box in an hlist [651](#) $\rangle \equiv$
if *list_ptr*(*p*) = *null* **then** *cur_h* \leftarrow *cur_h* + *width*(*p*)
else begin *save_h* \leftarrow *dvi_h*; *save_v* \leftarrow *dvi_v*; *cur_v* \leftarrow *base_line* + *shift_amount*(*p*);
 { shift the box down }
 temp_ptr \leftarrow *p*; *edge* \leftarrow *cur_h* + *width*(*p*);
 if *cur_dir* = *right_to_left* **then** *cur_h* \leftarrow *edge*;
 if *type*(*p*) = *vlist_node* **then** *vlist_out* **else** *hlist_out*;
 dvi_h \leftarrow *save_h*; *dvi_v* \leftarrow *save_v*; *cur_h* \leftarrow *edge*; *cur_v* \leftarrow *base_line*;
end

This code is used in section [650](#).

652. \langle Output a rule in an hlist [652](#) $\rangle \equiv$
if *is_running*(*rule_ht*) **then** *rule_ht* \leftarrow *height*(*this_box*);
if *is_running*(*rule_dp*) **then** *rule_dp* \leftarrow *depth*(*this_box*);
rule_ht \leftarrow *rule_ht* + *rule_dp*; { this is the rule thickness }
if (*rule_ht* > 0) \wedge (*rule_wd* > 0) **then** { we don't output empty rules }
 begin *synch_h*; *cur_v* \leftarrow *base_line* + *rule_dp*; *synch_v*; *dvi_out*(*set_rule*); *dvi_four*(*rule_ht*);
 dvi_four(*rule_wd*); *cur_v* \leftarrow *base_line*; *dvi_h* \leftarrow *dvi_h* + *rule_wd*;
 end

This code is used in section [650](#).

653. **define** *billion* \equiv *float_constant*(1000000000)
define *vet_glue*(#) \equiv *glue_temp* \leftarrow #;
 if *glue_temp* > *billion* **then** *glue_temp* \leftarrow *billion*
 else if *glue_temp* < -*billion* **then** *glue_temp* \leftarrow -*billion*
define *round_glue* \equiv *g* \leftarrow *glue_ptr*(*p*); *rule_wd* \leftarrow *width*(*g*) - *cur_g*;
 if *g_sign* \neq *normal* **then**
 begin if *g_sign* = *stretching* **then**
 begin if *stretch_order*(*g*) = *g_order* **then**
 begin *cur_glue* \leftarrow *cur_glue* + *stretch*(*g*); *vet_glue*(*float*(*glue_set*(*this_box*)) * *cur_glue*);
 cur_g \leftarrow *round*(*glue_temp*);
 end;
 end
 else if *shrink_order*(*g*) = *g_order* **then**
 begin *cur_glue* \leftarrow *cur_glue* - *shrink*(*g*); *vet_glue*(*float*(*glue_set*(*this_box*)) * *cur_glue*);
 cur_g \leftarrow *round*(*glue_temp*);
 end;
 end;
 rule_wd \leftarrow *rule_wd* + *cur_g*

\langle Move right or output leaders [653](#) $\rangle \equiv$
begin *round_glue*;
if *eTeX_ex* **then** \langle Handle a glue node for mixed direction typesetting [1696](#) \rangle ;
if *subtype*(*p*) \geq *a_leaders* **then**
 \langle Output leaders in an hlist, **goto** *fin_rule* if a rule or to *next_p* if done [654](#) \rangle ;
goto *move_past*;
end

This code is used in section [650](#).

654. \langle Output leaders in an hlist, **goto** *fin_rule* if a rule or to *next_p* if done 654 $\rangle \equiv$

```

begin leader_box  $\leftarrow$  leader_ptr(p);
if type(leader_box) = rule_node then
  begin rule_ht  $\leftarrow$  height(leader_box); rule_dp  $\leftarrow$  depth(leader_box); goto fin_rule;
end;
leader_wd  $\leftarrow$  width(leader_box);
if (leader_wd > 0)  $\wedge$  (rule_wd > 0) then
  begin rule_wd  $\leftarrow$  rule_wd + 10; { compensate for floating-point rounding }
  if cur_dir = right_to_left then cur_h  $\leftarrow$  cur_h - 10;
  edge  $\leftarrow$  cur_h + rule_wd; lx  $\leftarrow$  0;  $\langle$  Let cur_h be the position of the first box, and set leader_wd + lx to
    the spacing between corresponding parts of boxes 655  $\rangle$ ;
  while cur_h + leader_wd  $\leq$  edge do
     $\langle$  Output a leader box at cur_h, then advance cur_h by leader_wd + lx 656  $\rangle$ ;
  if cur_dir = right_to_left then cur_h  $\leftarrow$  edge
  else cur_h  $\leftarrow$  edge - 10;
  goto next_p;
end;
end

```

This code is used in section 653.

655. The calculations related to leaders require a bit of care. First, in the case of *a_leaders* (aligned leaders), we want to move *cur_h* to *left_edge* plus the smallest multiple of *leader_wd* for which the result is not less than the current value of *cur_h*; i.e., *cur_h* should become *left_edge* + *leader_wd* $\times \lceil (\text{cur_h} - \text{left_edge}) / \text{leader_wd} \rceil$. The program here should work in all cases even though some implementations of Pascal give nonstandard results for the **div** operation when *cur_h* is less than *left_edge*.

In the case of *c_leaders* (centered leaders), we want to increase *cur_h* by half of the excess space not occupied by the leaders; and in the case of *x_leaders* (expanded leaders) we increase *cur_h* by $1/(q+1)$ of this excess space, where *q* is the number of times the leader box will be replicated. Slight inaccuracies in the division might accumulate; half of this rounding error is placed at each end of the leaders.

\langle Let *cur_h* be the position of the first box, and set *leader_wd* + *lx* to the spacing between corresponding parts of boxes 655 $\rangle \equiv$

```

if subtype(p) = a_leaders then
  begin save_h  $\leftarrow$  cur_h; cur_h  $\leftarrow$  left_edge + leader_wd * ((cur_h - left_edge) div leader_wd);
  if cur_h < save_h then cur_h  $\leftarrow$  cur_h + leader_wd;
  end
else begin lq  $\leftarrow$  rule_wd div leader_wd; { the number of box copies }
  lr  $\leftarrow$  rule_wd mod leader_wd; { the remaining space }
  if subtype(p) = c_leaders then cur_h  $\leftarrow$  cur_h + (lr div 2)
  else begin lx  $\leftarrow$  lr div (lq + 1); cur_h  $\leftarrow$  cur_h + ((lr - (lq - 1) * lx) div 2);
  end;
end

```

This code is used in sections 654 and 736.

656. The ‘*synch*’ operations here are intended to decrease the number of bytes needed to specify horizontal and vertical motion in the DVI output.

```

⟨Output a leader box at cur_h, then advance cur_h by leader_wd + lx 656⟩ ≡
begin cur_v ← base_line + shift_amount(leader_box); synch_v; save_v ← dvi_v;
synch_h; save_h ← dvi_h; temp_ptr ← leader_box;
if cur_dir = right_to_left then cur_h ← cur_h + leader_wd;
outer_doing_leaders ← doing_leaders; doing_leaders ← true;
if type(leader_box) = vlist_node then vlist_out else hlist_out;
doing_leaders ← outer_doing_leaders; dvi_v ← save_v; dvi_h ← save_h; cur_v ← base_line;
cur_h ← save_h + leader_wd + lx;
end

```

This code is used in section 654.

657. The *vlist_out* routine is similar to *hlist_out*, but a bit simpler.

```

procedure vlist_out; {output a vlist_node box}
label move_past, fin_rule, next_p;
var left_edge: scaled; {the left coordinate for this box}
    top_edge: scaled; {the top coordinate for this box}
    save_h, save_v: scaled; {what dvi_h and dvi_v should pop to}
    this_box: pointer; {pointer to containing box}
    g_order: glue_ord; {applicable order of infinity for glue}
    g_sign: normal .. shrinking; {selects type of glue}
    p: pointer; {current position in the vlist}
    save_loc: integer; {DVI byte location upon entry}
    leader_box: pointer; {the leader box being replicated}
    leader_ht: scaled; {height of leader box being replicated}
    lx: scaled; {extra space between leader boxes}
    outer_doing_leaders: boolean; {were we doing leaders?}
    edge: scaled; {bottom boundary of leader space}
    glue_temp: real; {glue value before rounding}
    cur_glue: real; {glue seen so far}
    cur_g: scaled; {rounded equivalent of cur_glue times the glue ratio}
begin cur_g ← 0; cur_glue ← float_constant(0); this_box ← temp_ptr; g_order ← glue_order(this_box);
    g_sign ← glue_sign(this_box); p ← list_ptr(this_box); incr(cur_s);
if cur_s > 0 then dvi_out(push);
if cur_s > max_push then max_push ← cur_s;
    save_loc ← dvi_offset + dvi_ptr; left_edge ← cur_h; cur_v ← cur_v − height(this_box); top_edge ← cur_v;
while p ≠ null do ⟨Output node p for vlist_out and move to the next node, maintaining the condition
    cur_h = left_edge 658⟩;
    prune_movements(save_loc);
if cur_s > 0 then dvi_pop(save_loc);
    decr(cur_s);
end;

```

658. ⟨Output node *p* for *vlist_out* and move to the next node, maintaining the condition

```

    cur_h = left_edge 658⟩ ≡
begin if is_char_node(p) then confusion("vlistout")
else ⟨Output the non-char_node p for vlist_out 659⟩;
next_p: p ← link(p);
end

```

This code is used in section 657.

659. \langle Output the non-*char_node* p for *vlist_out* 659 $\rangle \equiv$
begin case *type*(p) **of**
hlist_node, *vlist_node*: \langle Output a box in a vlist 660 \rangle ;
rule_node: **begin** *rule_ht* \leftarrow *height*(p); *rule_dp* \leftarrow *depth*(p); *rule_wd* \leftarrow *width*(p); **goto** *fin_rule*;
end;
whatsit_node: \langle Output the *whatsit* node p in a vlist 1610 \rangle ;
glue_node: \langle Move down or output leaders 662 \rangle ;
kern_node: *cur_v* \leftarrow *cur_v* + *width*(p);
othercases *do_nothing*
endcases;
goto *next_p*;
fin_rule: \langle Output a rule in a vlist, **goto** *next_p* 661 \rangle ;
move_past: *cur_v* \leftarrow *cur_v* + *rule_ht*;
end

This code is used in section 658.

660. The *synch_v* here allows the DVI output to use one-byte commands for adjusting v in most cases, since the baselineskip distance will usually be constant.

\langle Output a box in a vlist 660 $\rangle \equiv$
if *list_ptr*(p) = *null* **then** *cur_v* \leftarrow *cur_v* + *height*(p) + *depth*(p)
else begin *cur_v* \leftarrow *cur_v* + *height*(p); *synch_v*; *save_h* \leftarrow *dvi_h*; *save_v* \leftarrow *dvi_v*;
if *cur_dir* = *right_to_left* **then** *cur_h* \leftarrow *left_edge* - *shift_amount*(p)
else *cur_h* \leftarrow *left_edge* + *shift_amount*(p); { shift the box right }
temp_ptr \leftarrow p ;
if *type*(p) = *vlist_node* **then** *vlist_out* **else** *hlist_out*;
dvi_h \leftarrow *save_h*; *dvi_v* \leftarrow *save_v*; *cur_v* \leftarrow *save_v* + *depth*(p); *cur_h* \leftarrow *left_edge*;
end

This code is used in section 659.

661. \langle Output a rule in a vlist, **goto** *next_p* 661 $\rangle \equiv$
if *is_running*(*rule_wd*) **then** *rule_wd* \leftarrow *width*(*this_box*);
rule_ht \leftarrow *rule_ht* + *rule_dp*; { this is the rule thickness }
cur_v \leftarrow *cur_v* + *rule_ht*;
if (*rule_ht* > 0) \wedge (*rule_wd* > 0) **then** { we don't output empty rules }
begin if *cur_dir* = *right_to_left* **then** *cur_h* \leftarrow *cur_h* - *rule_wd*;
synch_h; *synch_v*; *dvi_out*(*put_rule*); *dvi_four*(*rule_ht*); *dvi_four*(*rule_wd*); *cur_h* \leftarrow *left_edge*;
end;
goto *next_p*

This code is used in section 659.

662. \langle Move down or output leaders [662](#) $\rangle \equiv$

```

begin  $g \leftarrow glue\_ptr(p)$ ;  $rule\_ht \leftarrow width(g) - cur\_g$ ;
if  $g\_sign \neq normal$  then
  begin if  $g\_sign = stretching$  then
    begin if  $stretch\_order(g) = g\_order$  then
      begin  $cur\_glue \leftarrow cur\_glue + stretch(g)$ ;  $vet\_glue(float(glue\_set(this\_box)) * cur\_glue)$ ;
       $cur\_g \leftarrow round(glue\_temp)$ ;
      end;
    end
  else if  $shrink\_order(g) = g\_order$  then
    begin  $cur\_glue \leftarrow cur\_glue - shrink(g)$ ;  $vet\_glue(float(glue\_set(this\_box)) * cur\_glue)$ ;
     $cur\_g \leftarrow round(glue\_temp)$ ;
    end;
  end;
 $rule\_ht \leftarrow rule\_ht + cur\_g$ ;
if  $subtype(p) \geq a\_leaders$  then
   $\langle$  Output leaders in a vlist, goto  $fin\_rule$  if a rule or to  $next\_p$  if done 663  $\rangle$ ;
goto  $move\_past$ ;
end

```

This code is used in section [659](#).

663. \langle Output leaders in a vlist, **goto** fin_rule if a rule or to $next_p$ if done [663](#) $\rangle \equiv$

```

begin  $leader\_box \leftarrow leader\_ptr(p)$ ;
if  $type(leader\_box) = rule\_node$  then
  begin  $rule\_wd \leftarrow width(leader\_box)$ ;  $rule\_dp \leftarrow 0$ ; goto  $fin\_rule$ ;
end;
 $leader\_ht \leftarrow height(leader\_box) + depth(leader\_box)$ ;
if  $(leader\_ht > 0) \wedge (rule\_ht > 0)$  then
  begin  $rule\_ht \leftarrow rule\_ht + 10$ ; { compensate for floating-point rounding }
   $edge \leftarrow cur\_v + rule\_ht$ ;  $lx \leftarrow 0$ ;  $\langle$  Let  $cur\_v$  be the position of the first box, and set  $leader\_ht + lx$  to
  the spacing between corresponding parts of boxes 664  $\rangle$ ;
  while  $cur\_v + leader\_ht \leq edge$  do
     $\langle$  Output a leader box at  $cur\_v$ , then advance  $cur\_v$  by  $leader\_ht + lx$  665  $\rangle$ ;
     $cur\_v \leftarrow edge - 10$ ; goto  $next\_p$ ;
  end;
end

```

This code is used in section [662](#).

664. \langle Let cur_v be the position of the first box, and set $leader_ht + lx$ to the spacing between corresponding parts of boxes [664](#) $\rangle \equiv$

```

if  $subtype(p) = a\_leaders$  then
  begin  $save\_v \leftarrow cur\_v$ ;  $cur\_v \leftarrow top\_edge + leader\_ht * ((cur\_v - top\_edge) \text{ div } leader\_ht)$ ;
  if  $cur\_v < save\_v$  then  $cur\_v \leftarrow cur\_v + leader\_ht$ ;
  end
else begin  $lq \leftarrow rule\_ht \text{ div } leader\_ht$ ; { the number of box copies }
   $lr \leftarrow rule\_ht \text{ mod } leader\_ht$ ; { the remaining space }
  if  $subtype(p) = c\_leaders$  then  $cur\_v \leftarrow cur\_v + (lr \text{ div } 2)$ 
  else begin  $lx \leftarrow lr \text{ div } (lq + 1)$ ;  $cur\_v \leftarrow cur\_v + ((lr - (lq - 1) * lx) \text{ div } 2)$ ;
  end;
end

```

This code is used in sections [663](#) and [745](#).

665. When we reach this part of the program, *cur_v* indicates the top of a leader box, not its baseline.

```

⟨Output a leader box at cur_v, then advance cur_v by leader_ht + lx 665⟩ ≡
  begin if cur_dir = right_to_left then cur_h ← left_edge − shift_amount(leader_box)
  else cur_h ← left_edge + shift_amount(leader_box);
  synch_h; save_h ← dvi_h;
  cur_v ← cur_v + height(leader_box); synch_v; save_v ← dvi_v; temp_ptr ← leader_box;
  outer_doing_leaders ← doing_leaders; doing_leaders ← true;
  if type(leader_box) = vlist_node then vlist_out else hlist_out;
  doing_leaders ← outer_doing_leaders; dvi_v ← save_v; dvi_h ← save_h; cur_h ← left_edge;
  cur_v ← save_v − height(leader_box) + leader_ht + lx;
end

```

This code is used in section 663.

666. The *hlist_out* and *vlist_out* procedures are now complete, so we are ready for the *dvi_ship_out* routine that gets them started in the first place.

```

procedure dvi_ship_out(p : pointer); {output the box p}
  label done;
  var page_loc: integer; {location of the current bop}
  j, k: 0 .. 9; {indices to first ten count registers}
  s: pool_pointer; {index into str_pool}
  old_setting: 0 .. max_selector; {saved selector setting}
  begin if tracing_output > 0 then
    begin print_nl(""); print_ln; print("Completed_box_being_shipped_out");
    end;
  if term_offset > max_print_line − 9 then print_ln
  else if (term_offset > 0) ∨ (file_offset > 0) then print_char(" ");
  print_char("["; j ← 9;
  while (count(j) = 0) ∧ (j > 0) do decr(j);
  for k ← 0 to j do
    begin print_int(count(k));
    if k < j then print_char(".");
    end;
  update_terminal;
  if tracing_output > 0 then
    begin print_char("]"); begin_diagnostic; show_box(p); end_diagnostic(true);
    end;
  ⟨Ship box p out 668⟩;
  if eTeX_ex then ⟨Check for LR anomalies at the end of ship_out 1727⟩;
  if tracing_output ≤ 0 then print_char("]");
  dead_cycles ← 0; update_terminal; {progress report}
  ⟨Flush the box from memory, showing statistics if requested 667⟩;
end;

```

667. \langle Flush the box from memory, showing statistics if requested [667](#) $\rangle \equiv$

```

stat if tracing_stats > 1 then
  begin print_nl("Memory_usage_before:"); print_int(var_used); print_char("&");
    print_int(dyn_used); print_char(";");
  end;
tats
flush_node_list(p);
stat if tracing_stats > 1 then
  begin print("_after:"); print_int(var_used); print_char("&"); print_int(dyn_used);
    print(";still_untouched:"); print_int(hi_mem_min - lo_mem_max - 1); print_ln;
  end;
tats

```

This code is used in sections [666](#) and [750](#).

668. \langle Ship box p out [668](#) $\rangle \equiv$

\langle Update the values of max_h and max_v ; but if the page is too large, **goto** *done* [669](#) \rangle ;

\langle Initialize variables as *ship_out* begins [645](#) \rangle ;

```

page_loc  $\leftarrow$  dvi_offset + dvi_ptr; dvi_out(bop);
for  $k \leftarrow 0$  to 9 do dvi_four(count( $k$ ));
dvi_four(last_bop); last_bop  $\leftarrow$  page_loc; cur_v  $\leftarrow$  height( $p$ ) + v_offset; temp_ptr  $\leftarrow$   $p$ ;
if type( $p$ ) = vlist_node then vlist_out else hlist_out;
dvi_out(eop); incr(total_pages); cur_s  $\leftarrow$  -1;
done:

```

This code is used in section [666](#).

669. Sometimes the user will generate a huge page because other error messages are being ignored. Such pages are not output to the dvi file, since they may confuse the printing software.

\langle Update the values of max_h and max_v ; but if the page is too large, **goto** *done* [669](#) $\rangle \equiv$

```

if (height( $p$ ) > max_dimen)  $\vee$  (depth( $p$ ) > max_dimen)  $\vee$ 
  (height( $p$ ) + depth( $p$ ) + v_offset > max_dimen)  $\vee$  (width( $p$ ) + h_offset > max_dimen) then
  begin print_err("Huge_page_cannot_be_shipped_out");
    help2("The_page_just_created_is_more_than_18_feet_tall_or")
    ("more_than_18_feet_wide,_so_I_suspect_something_went_wrong."); error;
  if tracing_output  $\leq 0$  then
    begin begin_diagnostic; print_nl("The_following_box_has_been_deleted:"); show_box( $p$ );
      end_diagnostic(true);
    end;
  goto done;
end;
if height( $p$ ) + depth( $p$ ) + v_offset > max_v then max_v  $\leftarrow$  height( $p$ ) + depth( $p$ ) + v_offset;
if width( $p$ ) + h_offset > max_h then max_h  $\leftarrow$  width( $p$ ) + h_offset

```

This code is used in sections [668](#) and [751](#).

670. At the end of the program, we must finish things off by writing the postamble. If *total_pages* = 0, the DVI file was never opened. If *total_pages* \geq 65536, the DVI file will lie. And if *max_push* \geq 65536, the user deserves whatever chaos might ensue.

An integer variable *k* will be declared for use by this routine.

```

⟨ Finish the DVI file 670 ⟩ ≡
  while cur_s > -1 do
    begin if cur_s > 0 then dvi_out(pop)
    else begin dvi_out(eop); incr(total_pages);
      end;
    decr(cur_s);
  end;
if total_pages = 0 then print_nl("No_pages_of_output.")
else begin dvi_out(post); { beginning of the postamble }
  dvi_four(last_bop); last_bop ← dvi_offset + dvi_ptr - 5; { post location }
  dvi_four(25400000); dvi_four(473628672); { conversion ratio for sp }
  prepare_mag; dvi_four(mag); { magnification factor }
  dvi_four(max_v); dvi_four(max_h);
  dvi_out(max_push div 256); dvi_out(max_push mod 256);
  dvi_out((total_pages div 256) mod 256); dvi_out(total_pages mod 256);
  ⟨ Output the font definitions for all fonts that were used 671 ⟩;
  dvi_out(post_post); dvi_four(last_bop); dvi_out(id_byte);
  k ← 4 + ((dvi_buf_size - dvi_ptr) mod 4); { the number of 223's }
  while k > 0 do
    begin dvi_out(223); decr(k);
    end;
  ⟨ Empty the last bytes out of dvi_buf 626 ⟩;
  print_nl("Output_written_on_"); slow_print(output_file_name); print("_"); print_int(total_pages);
  print("_page");
  if total_pages ≠ 1 then print_char("s");
  print(","); print_int(dvi_offset + dvi_ptr); print("_bytes."); b_close(dvi_file);
end

```

This code is used in section 1511.

```

671. ⟨ Output the font definitions for all fonts that were used 671 ⟩ ≡
  while font_ptr > font_base do
    begin if font_used[font_ptr] then dvi_font_def(font_ptr);
      decr(font_ptr);
    end

```

This code is used in section 670.

672. pdfTeX basic. Initialize pdfTeX's parameters to some useful default value. Helpful in case one forgets to set them during INITEX run.

⟨Initialize table entries (done by INITEX only) 182⟩ +≡

```
pdf_h_origin ← (one_hundred_inch + 50) div 100; pdf_v_origin ← (one_hundred_inch + 50) div 100;
pdf_compress_level ← 9; pdf_objcompresslevel ← 0; pdf_decimal_digits ← 3; pdf_image_resolution ← 72;
pdf_major_version ← 1; pdf_minor_version ← 4; pdf_gamma ← 1000; pdf_image_gamma ← 2200;
pdf_image_hicolor ← 1; pdf_image_apply_gamma ← 0; pdf_px_dimen ← one_bp; pdf_draftmode ← 0;
```

673. The subroutines define the corresponding macros so we can use them in C.

```

define flushable(#)  $\equiv$  (# = str_ptr - 1)
define is_valid_char(#)  $\equiv$  ((font_bc[f]  $\leq$  #)  $\wedge$  (#  $\leq$  font_ec[f])  $\wedge$  char_exists(char_info(f)(#)))

function get_pdf_compress_level: integer;
  begin get_pdf_compress_level  $\leftarrow$  pdf_compress_level;
  end;

function get_pdf_suppress_warning_dup_map: integer;
  begin get_pdf_suppress_warning_dup_map  $\leftarrow$  pdf_suppress_warning_dup_map;
  end;

function get_pdf_suppress_warning_page_group: integer;
  begin get_pdf_suppress_warning_page_group  $\leftarrow$  pdf_suppress_warning_page_group;
  end;

function get_pdf_suppress_ptex_info: integer;
  begin get_pdf_suppress_ptex_info  $\leftarrow$  pdf_suppress_ptex_info;
  end;

function get_pdf_omit_charset: integer;
  begin get_pdf_omit_charset  $\leftarrow$  pdf_omit_charset;
  end;

function get_nullfont: internal_font_number;
  begin get_nullfont  $\leftarrow$  null_font;
  end;

function get_fontbase: internal_font_number;
  begin get_fontbase  $\leftarrow$  font_base;
  end;

function get_nullcs: pointer;
  begin get_nullcs  $\leftarrow$  null_cs;
  end;

function get_nullptr: pointer;
  begin get_nullptr  $\leftarrow$  null;
  end;

function get_tex_int(code : integer): integer;
  begin get_tex_int  $\leftarrow$  int_par(code);
  end;

function get_tex_dimen(code : integer): scaled;
  begin get_tex_dimen  $\leftarrow$  dimen_par(code);
  end;

function get_x_height(f : internal_font_number): scaled;
  begin get_x_height  $\leftarrow$  x_height(f);
  end;

function get_charwidth(f : internal_font_number; c : eight_bits): scaled;
  begin if is_valid_char(c) then get_charwidth  $\leftarrow$  char_width(f)(char_info(f)(c))
  else get_charwidth  $\leftarrow$  0;
  end;

function get_charheight(f : internal_font_number; c : eight_bits): scaled;
  begin if is_valid_char(c) then get_charheight  $\leftarrow$  char_height(f)(height_depth(char_info(f)(c)))
  else get_charheight  $\leftarrow$  0;
  end;

function get_chardepth(f : internal_font_number; c : eight_bits): scaled;
  begin if is_valid_char(c) then get_chardepth  $\leftarrow$  char_depth(f)(height_depth(char_info(f)(c)))
  else get_chardepth  $\leftarrow$  0;
  end;

function get_quad(f : internal_font_number): scaled;

```

```

begin get_quad  $\leftarrow$  quad(f);
end;
function get_slant(f : internal_font_number): scaled;
  begin get_slant  $\leftarrow$  slant(f);
end;
function new_dummy_font: internal_font_number;
  begin new_dummy_font  $\leftarrow$  read_font_info(null_cs, "dummy", "", -1000);
end;

```

674. Helper for debugging purposes:

```

procedure short_display_n(p, m : integer); { prints highlights of list p }
  var n: integer; { for replacement counts }
  i: integer;
  begin i  $\leftarrow$  0; font_in_short_display  $\leftarrow$  null_font;
  if p = null then return;
  while p > mem_min do
    begin if is_char_node(p) then
      begin if p  $\leq$  mem_end then
        begin if font(p)  $\neq$  font_in_short_display then
          begin if (font(p) < font_base)  $\vee$  (font(p) > font_max) then print_char("*")
          else print_font_identifier(font(p));
          print_char("□"); font_in_short_display  $\leftarrow$  font(p);
          end;
          print_ASCII(qo(character(p)));
          end;
        end
      else begin if (type(p) = glue_node)  $\vee$  (type(p) = disc_node)  $\vee$  (type(p) = penalty_node)  $\vee$  ((type(p) =
        kern_node)  $\wedge$  (subtype(p) = explicit)) then incr(i);
        if i  $\geq$  m then return;
        if (type(p) = disc_node) then
          begin print("|"); short_display(pre_break(p)); print("|"); short_display(post_break(p));
          print("|"); n  $\leftarrow$  replace_count(p);
          while n > 0 do
            begin if link(p)  $\neq$  null then p  $\leftarrow$  link(p);
            decr(n);
            end;
          end
          else  $\langle$  Print a short indication of the contents of node p 193  $\rangle$ ;
          end;
          p  $\leftarrow$  link(p);
          if p = null then return;
          end;
        update_terminal;
      end;

```

675. Sometimes it is necessary to allocate memory for PDF output that cannot be deallocated then, so we use *pdf_mem* for this purpose.

\langle Constants in the outer block 11 $\rangle + \equiv$

```

inf_pdf_mem_size = 10000; { min size of the pdf_mem array }
sup_pdf_mem_size = 10000000; { max size of the pdf_mem array }

```

676. \langle Global variables 13 $\rangle + \equiv$

pdf_mem_size: integer;

pdf_mem: \uparrow integer;

pdf_mem_ptr: integer;

677. \langle Set initial values of key variables 21 $\rangle + \equiv$

pdf_mem_ptr \leftarrow 1; { the first word is not used so we can use zero as a value for testing whether a pointer to *pdf_mem* is valid }

pdf_mem_size \leftarrow *inf_pdf_mem_size*; { allocated size of *pdf_mem* array }

678. We use *pdf_get_mem* to allocate memory in *pdf_mem*.

function *pdf_get_mem*(*s* : integer): integer; { allocate *s* words in *pdf_mem* }

var *a*: integer;

begin if *s* > *sup_pdf_mem_size* - *pdf_mem_ptr* **then**

overflow("PDF_memory_size", *pdf_mem_size*);

if *pdf_mem_ptr* + *s* > *pdf_mem_size* **then**

begin *a* \leftarrow 0.2 * *pdf_mem_size*;

if *pdf_mem_ptr* + *s* > *pdf_mem_size* + *a* **then** *pdf_mem_size* \leftarrow *pdf_mem_ptr* + *s*

else if *pdf_mem_size* < *sup_pdf_mem_size* - *a* **then** *pdf_mem_size* \leftarrow *pdf_mem_size* + *a*

else *pdf_mem_size* \leftarrow *sup_pdf_mem_size*;

pdf_mem \leftarrow *xrealloc_array*(*pdf_mem*, integer, *pdf_mem_size*);

end;

pdf_get_mem \leftarrow *pdf_mem_ptr*; *pdf_mem_ptr* \leftarrow *pdf_mem_ptr* + *s*;

end;

679. pdfTeX output low-level subroutines. We use the similar subroutines to handle the output buffer for PDF output. When compress is used, the state of writing to buffer is held in *zip_write_state*. We must write the header of PDF output file in initialization to ensure that it will be the first written bytes.

⟨ Constants in the outer block 11 ⟩ +≡

pdf_op_buf_size = 16384; { size of the PDF output buffer }

inf_pdf_os_buf_size = 1; { initial value of *pdf_os_buf_size* }

sup_pdf_os_buf_size = 5000000; { arbitrary upper hard limit of *pdf_os_buf_size* }

pdf_os_max_objs = 100; { maximum number of objects in object stream }

680. The following macros are similar as for DVI buffer handling:

```

define pdf_offset  $\equiv$  (pdf_gone + pdf_ptr)
    { the file offset of last byte in PDF buffer that pdf_ptr points to }
define no_zip  $\equiv$  0 { no ZIP compression }
define zip_writing  $\equiv$  1 { ZIP compression being used }
define zip_finish  $\equiv$  2 { finish ZIP compression }
define pdf_quick_out(#)  $\equiv$  { output a byte to PDF buffer without checking of overflow }
    begin pdf_buf[pdf_ptr]  $\leftarrow$  #; incr(pdf_ptr);
    end
define pdf_room(#)  $\equiv$  { make sure that there are at least  $n$  bytes free in PDF buffer }
    begin if pdf_os_mode  $\wedge$  (# + pdf_ptr > pdf_buf_size) then pdf_os_get_os_buf(#)
    else if  $\neg$ pdf_os_mode  $\wedge$  (# > pdf_buf_size) then overflow("PDF_output_buffer", pdf_op_buf_size)
    else if  $\neg$ pdf_os_mode  $\wedge$  (# + pdf_ptr > pdf_buf_size) then pdf_flush;
    end
define pdf_out(#)  $\equiv$  { do the same as pdf_quick_out and flush the PDF buffer if necessary }
    begin pdf_room(1); pdf_quick_out(#);
    end

(Global variables 13) +=
pdf_file: byte_file; { the PDF output file }
pdf_buf:  $\uparrow$ eight_bits; { pointer to the PDF output buffer or PDF object stream buffer }
pdf_buf_size: integer; { end of PDF output buffer or PDF object stream buffer }
pdf_ptr: integer; { pointer to the first unused byte in the PDF buffer or object stream buffer }
pdf_op_buf:  $\uparrow$ eight_bits; { the PDF output buffer }
pdf_os_buf:  $\uparrow$ eight_bits; { the PDF object stream buffer }
pdf_os_buf_size: integer; { current size of the PDF object stream buffer, grows dynamically }
pdf_os_objnum:  $\uparrow$ integer; { array of object numbers within object stream }
pdf_os_objoff:  $\uparrow$ integer; { array of object offsets within object stream }
pdf_os_objidx: pointer; { pointer into pdf_os_objnum and pdf_os_objoff }
pdf_os_cntr: integer; { counter for object stream objects }
pdf_op_ptr: integer; { store for PDF buffer pdf_ptr while inside object streams }
pdf_os_ptr: integer; { store for object stream pdf_ptr while outside object streams }
pdf_os_mode: boolean; { true if producing object stream }
pdf_os_enable: boolean; { true if object streams are globally enabled }
pdf_os_cur_objnum: integer; { number of current object stream object }
pdf_gone: longinteger; { number of bytes that were flushed to output }
pdf_save_offset: longinteger; { to save pdf_offset }
zip_write_state: integer; { which state of compression we are in }
fixed_pdf_major_version: integer; { fixed major part of the PDF version }
fixed_pdf_minor_version: integer; { fixed minor part of the PDF version }
fixed_pdf_objcompresslevel: integer; { fixed level for activating PDF object streams }
pdf_version_written: boolean; { flag if the PDF version has been written }
fixed_pdfoutput: integer; { fixed output format }
fixed_pdfoutput_set: boolean; { fixed_pdfoutput has been set? }
fixed_gamma: integer;
fixed_image_gamma: integer;
fixed_image_hicolor: boolean;
fixed_image_apply_gamma: integer;
epochseconds: integer;
microseconds: integer;
fixed_pdf_draftmode: integer; { fixed pdfdraftmode }
fixed_pdf_draftmode_set: boolean; { fixed_pdf_draftmode has been set? }
pdf_page_group_val: integer;

```

681. \langle Set initial values of key variables 21 $\rangle + \equiv$

```
pdf_gone  $\leftarrow$  0; pdf_os_mode  $\leftarrow$  false; pdf_ptr  $\leftarrow$  0; pdf_op_ptr  $\leftarrow$  0; pdf_os_ptr  $\leftarrow$  0;
pdf_os_cur_objnum  $\leftarrow$  0; pdf_os_cntr  $\leftarrow$  0; pdf_buf_size  $\leftarrow$  pdf_op_buf_size;
pdf_os_buf_size  $\leftarrow$  inf_pdf_os_buf_size; pdf_buf  $\leftarrow$  pdf_op_buf; pdf_seek_write_length  $\leftarrow$  false;
zip_write_state  $\leftarrow$  no_zip; pdf_version_written  $\leftarrow$  false; fixed_pdfoutput_set  $\leftarrow$  false;
fixed_pdf_draftmode_set  $\leftarrow$  false;
```

682.

function *fix_int*(*val*, *min*, *max* : integer): integer;

```
begin if val < min then fix_int  $\leftarrow$  min
```

```
else if val > max then fix_int  $\leftarrow$  max
```

```
    else fix_int  $\leftarrow$  val;
```

```
end;
```

683. This ensures that *pdf_major_version* and *pdf_minor_version* are set to reasonable values before any bytes have been written to the generated PDF file. We also save their current values in case the user tries to change them later, along with *pdf_objcompresslevel*, *pdf_image_hicolor*, and various other parameters that must be fixed before any PDF output happens.

Here also the PDF file is opened by *ensure_pdf_open* and the PDF header is written.

```

procedure check_pdfversion;
begin if  $\neg$ pdf_version_written then
  begin pdf_version_written  $\leftarrow$  true;
  if pdf_major_version < 1 then
    begin print_err("pdfTeX_error_␣(invalid_␣pdfmajorversion)"); print_ln;
    help2("The_␣pdfmajorversion_␣must_␣be_␣1_␣or_␣greater.")
    ("I_␣changed_␣this_␣to_␣1."); int_error(pdf_major_version); pdf_major_version  $\leftarrow$  1;
    end;
  if (pdf_minor_version < 0)  $\vee$  (pdf_minor_version > 9) then
    begin print_err("pdfTeX_error_␣(invalid_␣pdfminorversion)"); print_ln;
    help2("The_␣pdfminorversion_␣must_␣be_␣between_␣0_␣and_␣9.")
    ("I_␣changed_␣this_␣to_␣4."); int_error(pdf_minor_version); pdf_minor_version  $\leftarrow$  4;
    end;
  fixed_pdf_major_version  $\leftarrow$  pdf_major_version; fixed_pdf_minor_version  $\leftarrow$  pdf_minor_version;
  fixed_gamma  $\leftarrow$  fix_int(pdf_gamma, 0, 1000000);
  fixed_image_gamma  $\leftarrow$  fix_int(pdf_image_gamma, 0, 1000000);
  fixed_image_hicolor  $\leftarrow$  fix_int(pdf_image_hicolor, 0, 1);
  fixed_image_apply_gamma  $\leftarrow$  fix_int(pdf_image_apply_gamma, 0, 1);
  fixed_pdf_objcompresslevel  $\leftarrow$  fix_int(pdf_objcompresslevel, 0, 3);
  fixed_pdf_draftmode  $\leftarrow$  fix_int(pdf_draftmode, 0, 1);
  fixed_inclusion_copy_font  $\leftarrow$  fix_int(pdf_inclusion_copy_font, 0, 1);
  if ((fixed_pdf_major_version > 1)  $\vee$  (fixed_pdf_minor_version  $\geq$  5))  $\wedge$  (fixed_pdf_objcompresslevel > 0)
    then pdf_os_enable  $\leftarrow$  true
  else begin if fixed_pdf_objcompresslevel > 0 then
    begin pdf_warning("Object_␣streams",
      "\pdfobjcompresslevel_␣>␣0_␣requires_␣PDF-1.5_␣or_␣greater.␣Object_␣streams_␣disabled_␣now",
      true, true); fixed_pdf_objcompresslevel  $\leftarrow$  0;
    end;
    pdf_os_enable  $\leftarrow$  false;
  end;
  ensure_pdf_open; fix_pdfoutput; pdf_print("%PDF-"); pdf_print_int(fixed_pdf_major_version);
  pdf_print("."); pdf_print_int.ln(fixed_pdf_minor_version); pdf_print(""); pdf_out(208); { 'P' + 128 }
  pdf_out(212); { 'T' + 128 }
  pdf_out(197); { 'E' + 128 }
  pdf_out(216); { 'X' + 128 }
  pdf_print_nl;
end
else begin
  if (fixed_pdf_minor_version  $\neq$  pdf_minor_version)  $\vee$  (fixed_pdf_major_version  $\neq$  pdf_major_version)
    then pdf_error("setup",
      "PDF_␣version_␣cannot_␣be_␣changed_␣after_␣data_␣is_␣written_␣to_␣the_␣PDF_␣file");
  end;
end;

```

684. Checks that we have a name for the generated PDF file and that it's open.

```

procedure ensure_pdf_open;
  begin if output_file_name  $\neq$  0 then return;
  if job_name = 0 then open_log_file;
  pack_job_name("pdf");
  if fixed_pdf_draftmode = 0 then
    while  $\neg$ b_open_out(pdf_file) do prompt_file_name("file_name_for_output", "pdf");
  output_file_name  $\leftarrow$  b_make_name_string(pdf_file);
end;

```

685. The PDF buffer is flushed by calling *pdf_flush*, which checks the variable *zip_write_state* and will compress the buffer before flushing if necessary. We call *pdf_begin_stream* to begin a stream and *pdf_end_stream* to finish it. The stream contents will be compressed if compression is turn on.

```

procedure pdf_flush; { flush out the pdf_buf }
  var saved_pdf_gone: longinteger;
  begin if  $\neg$ pdf_os_mode then
    begin saved_pdf_gone  $\leftarrow$  pdf_gone;
    case zip_write_state of
      no_zip: if pdf_ptr > 0 then
        begin if fixed_pdf_draftmode = 0 then write_pdf(0, pdf_ptr - 1);
        pdf_gone  $\leftarrow$  pdf_gone + pdf_ptr; pdf_last_byte  $\leftarrow$  pdf_buf[pdf_ptr - 1];
        end;
      zip_writing: if fixed_pdf_draftmode = 0 then write_zip(false);
      zip_finish: begin if fixed_pdf_draftmode = 0 then write_zip(true);
      zip_write_state  $\leftarrow$  no_zip;
      end;
    end; pdf_ptr  $\leftarrow$  0;
    if saved_pdf_gone > pdf_gone then
      pdf_error("file_size", "File_size_exceeds_architectural_limits(pdf_gone_wraps_around)");
    end;
  end;

procedure pdf_begin_stream; { begin a stream }
  begin pdf_print_ln("/Length#####"); pdf_seek_write_length  $\leftarrow$  true;
  { fill in length at pdf_end_stream call }
  pdf_stream_length_offset  $\leftarrow$  pdf_offset - 11; pdf_stream_length  $\leftarrow$  0; pdf_last_byte  $\leftarrow$  0;
  if pdf_compress_level > 0 then
    begin pdf_print_ln("/Filter/FlateDecode"); pdf_print_ln(">>"); pdf_print_ln("stream"); pdf_flush;
    zip_write_state  $\leftarrow$  zip_writing;
    end
  else begin pdf_print_ln(">>"); pdf_print_ln("stream"); pdf_save_offset  $\leftarrow$  pdf_offset;
  end;
end;

procedure pdf_end_stream; { end a stream }
  begin if zip_write_state = zip_writing then zip_write_state  $\leftarrow$  zip_finish
  else pdf_stream_length  $\leftarrow$  pdf_offset - pdf_save_offset;
  pdf_flush;
  if pdf_seek_write_length then write_stream_length(pdf_stream_length, pdf_stream_length_offset);
  pdf_seek_write_length  $\leftarrow$  false; pdf_out(pdf_new_line_char); pdf_print_ln("endstream"); pdf_end_obj;
end;

```

686. Basic printing procedures for PDF output are very similar to TeX basic printing ones but the output is going to PDF buffer. Subroutines with suffix *_ln* append a new-line character to the PDF output.

```

define pdf_new_line_char  $\equiv$  10 { new-line character for UNIX platforms }
define pdf_print_nl  $\equiv$  { output a new-line character to PDF buffer }
    pdf_out(pdf_new_line_char)
define pdf_print_ln( $\#$ )  $\equiv$  { print out a string to PDF buffer followed by a new-line character }
    begin pdf_print( $\#$ ); pdf_print_nl;
    end
define pdf_print_int_ln( $\#$ )  $\equiv$  { print out an integer to PDF buffer followed by a new-line character }
    begin pdf_print_int( $\#$ ); pdf_print_nl;
    end

(Declare procedures that need to be declared forward for pdfTeX 686)  $\equiv$ 
procedure pdf_error( $t, p : \text{str\_number}$ );
    begin normalize_selector; print_err("pdfTeX_error");
    if  $t \neq 0$  then
        begin print("_"); print( $t$ ); print(" ");
        end;
    print(":_"); print( $p$ ); succumb;
    end;
procedure pdf_warning( $t, p : \text{str\_number}$ ; prepend_nl, append_nl : boolean);
    begin if interaction = error_stop_mode then wake_up_terminal;
    if prepend_nl then print_ln;
    print("pdfTeX_warning");
    if  $t \neq 0$  then
        begin print("_"); print( $t$ ); print(" ");
        end;
    print(":_"); print( $p$ );
    if append_nl then print_ln;
    if history = spotless then history  $\leftarrow$  warning_issued;
    end;
procedure pdf_os_get_os_buf( $s : \text{integer}$ );
    { check that  $s$  bytes more fit into pdf_os_buf; increase it if required }
    var  $a : \text{integer}$ ;
    begin if  $s > \text{sup\_pdf\_os\_buf\_size} - \text{pdf\_ptr}$  then
        overflow("PDF_object_stream_buffer", pdf_os_buf_size);
    if  $\text{pdf\_ptr} + s > \text{pdf\_os\_buf\_size}$  then
        begin  $a \leftarrow 0.2 * \text{pdf\_os\_buf\_size}$ ;
        if  $\text{pdf\_ptr} + s > \text{pdf\_os\_buf\_size} + a$  then pdf_os_buf_size  $\leftarrow$  pdf_ptr +  $s$ 
        else if  $\text{pdf\_os\_buf\_size} < \text{sup\_pdf\_os\_buf\_size} - a$  then pdf_os_buf_size  $\leftarrow$  pdf_os_buf_size +  $a$ 
        else pdf_os_buf_size  $\leftarrow$  sup_pdf_os_buf_size;
        pdf_os_buf  $\leftarrow$  xrealloc_array(pdf_os_buf, eight_bits, pdf_os_buf_size); pdf_buf  $\leftarrow$  pdf_os_buf;
        pdf_buf_size  $\leftarrow$  pdf_os_buf_size;
        end;
    end;
procedure remove_last_space;
    begin if ( $\text{pdf\_ptr} > 0$ )  $\wedge$  ( $\text{pdf\_buf}[\text{pdf\_ptr} - 1] = 32$ ) then decr(pdf_ptr);
    end;
procedure pdf_print_octal( $n : \text{integer}$ ); { prints an integer in octal form to PDF buffer }
    var  $k : 0 \dots 23$ ; { index to current digit; we assume that  $n < 10^{23}$  }
    begin  $k \leftarrow 0$ ;
    repeat  $\text{dig}[k] \leftarrow n \bmod 8$ ;  $n \leftarrow n \text{ div } 8$ ; incr( $k$ );
    until  $n = 0$ ;

```

```

if  $k = 1$  then
  begin pdf_out("0"); pdf_out("0");
  end;
if  $k = 2$  then pdf_out("0");
while  $k > 0$  do
  begin decr( $k$ ); pdf_out("0" + dig[ $k$ ]);
  end;
end;
procedure pdf_print_char( $f$  : internal_font_number;  $c$  : integer);
  { print out a character to PDF buffer; the character will be printed in octal form in the following
  cases: chars  $\text{:=}$  32, backslash (92), left parenthesis (40) and right parenthesis (41) }
  begin pdf_mark_char( $f, c$ );
  if  $(c \leq 32) \vee (c = 92) \vee (c = 40) \vee (c = 41) \vee (c > 127)$  then
    begin pdf_out(92); { output a backslash }
    pdf_print_octal( $c$ );
    end
  else pdf_out( $c$ );
  end;
procedure pdf_print( $s$  : str_number); { print out a string to PDF buffer }
  var  $j$  : pool_pointer; { current character code position }
   $c$  : integer;
  begin  $j \leftarrow \text{str\_start}[s]$ ;
  while  $j < \text{str\_start}[s + 1]$  do
    begin  $c \leftarrow \text{str\_pool}[j]$ ; pdf_out( $c$ ); incr( $j$ );
    end;
  end;
function str_in_str( $s, r$  : str_number;  $i$  : integer): boolean; { test equality of strings }
  label not_found; { loop exit }
  var  $j, k$  : pool_pointer; { running indices }
  begin str_in_str  $\leftarrow \text{false}$ ;
  if length( $s$ ) <  $i$  + length( $r$ ) then return;
   $j \leftarrow i + \text{str\_start}[s]$ ;  $k \leftarrow \text{str\_start}[r]$ ;
  while  $(j < \text{str\_start}[s + 1]) \wedge (k < \text{str\_start}[r + 1])$  do
    begin if str_pool[ $j$ ]  $\neq$  str_pool[ $k$ ] then return;
    incr( $j$ ); incr( $k$ );
    end;
  str_in_str  $\leftarrow \text{true}$ ;
  end;
procedure pdf_print_int( $n$  : longinteger); { print out a integer to PDF buffer }
  var  $k$  : integer; { index to current digit ( $0 \leq k \leq 23$ ); we assume that  $n < 10^{23}$  }
   $m$  : longinteger; { used to negate  $n$  in possibly dangerous cases }
  begin  $k \leftarrow 0$ ;
  if  $n < 0$  then
    begin pdf_out("-");
    if  $n > -1000000000$  then negate( $n$ )
    else begin  $m \leftarrow -1 - n$ ;  $n \leftarrow m \text{ div } 10$ ;  $m \leftarrow (m \bmod 10) + 1$ ;  $k \leftarrow 1$ ;
    if  $m < 10$  then dig[0]  $\leftarrow m$ 
    else begin dig[0]  $\leftarrow 0$ ; incr( $n$ );
    end;
    end;
  end;
  end;
  repeat dig[ $k$ ]  $\leftarrow n \bmod 10$ ;  $n \leftarrow n \text{ div } 10$ ; incr( $k$ );

```

```

until  $n = 0$ ;
pdf_room( $k$ );
while  $k > 0$  do
  begin  $\text{decr}(k)$ ; pdf_quick_out("0" +  $\text{dig}[k]$ );
  end;
end;
procedure pdf_print_two( $n$  : integer); { prints two least significant digits in decimal form to PDF buffer }
  begin  $n \leftarrow \text{abs}(n) \bmod 100$ ; pdf_out("0" + ( $n \text{ div } 10$ )); pdf_out("0" + ( $n \bmod 10$ ));
  end;
function tokens_to_string( $p$  : pointer): str_number; { return a string from tokens list }
  begin if selector = new_string then
    pdf_error("tokens", "tokens_to_string() called while selector = new_string");
    old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string; show_token_list(link( $p$ ), null, pool_size - pool_ptr);
    selector  $\leftarrow$  old_setting; last_tokens_string  $\leftarrow$  make_string; tokens_to_string  $\leftarrow$  last_tokens_string;
  end;

```

See also sections 689, 698, 699, 700, 703, 1543, and 1553.

This code is used in section 190.

687. To print *scaled* value to PDF output we need some subroutines to ensure accuracy.

```

define max_integer  $\equiv$  "7FFFFFFF" {  $2^{31} - 1$  }
define call_func( $\#$ )  $\equiv$ 
  begin if  $\# \neq 0$  then do_nothing
  end

⟨Global variables 13⟩  $\equiv$ 
one_bp: scaled; { scaled value corresponds to 1bp }
one_hundred_bp: scaled; { scaled value corresponds to 100bp }
one_hundred_inch: scaled; { scaled value corresponds to 100in }
ten_pow: array [0 .. 9] of integer; {  $10^0..10^9$  }
scaled_out: integer; { amount of scaled that was taken out in divide_scaled }
init_pdf_output: boolean;

```

688. ⟨Set initial values of key variables 21⟩ \equiv

```

one_bp  $\leftarrow$  65782; { 65781.76 }
one_hundred_bp  $\leftarrow$  6578176; one_hundred_inch  $\leftarrow$  473628672; ten_pow[0]  $\leftarrow$  1;
for  $i \leftarrow 1$  to 9 do ten_pow[ $i$ ]  $\leftarrow$  10 * ten_pow[ $i - 1$ ];
init_pdf_output  $\leftarrow$  false;

```


689. The following function divides s by m . dd is number of decimal digits.

⟨Declare procedures that need to be declared forward for pdfTeX 686⟩ +≡

```

function divide_scaled( $s, m : \text{scaled}; dd : \text{integer}$ ): scaled;
  var  $q, r$ : scaled;  $sign, i$ : integer;
  begin  $sign \leftarrow 1$ ;
  if  $s < 0$  then
    begin  $sign \leftarrow -sign$ ;  $s \leftarrow -s$ ;
    end;
  if  $m < 0$  then
    begin  $sign \leftarrow -sign$ ;  $m \leftarrow -m$ ;
    end;
  if  $m = 0$  then pdf_error("arithmetic", "divided_by_zero")
  else if  $m \geq (\text{max\_integer} \text{ div } 10)$  then pdf_error("arithmetic", "number_too_big");
   $q \leftarrow s \text{ div } m$ ;  $r \leftarrow s \text{ mod } m$ ;
  for  $i \leftarrow 1$  to  $dd$  do
    begin  $q \leftarrow 10 * q + (10 * r) \text{ div } m$ ;  $r \leftarrow (10 * r) \text{ mod } m$ ;
    end;
  if  $2 * r \geq m$  then
    begin incr( $q$ );  $r \leftarrow r - m$ ;
    end;
   $scaled\_out \leftarrow sign * (s - (r \text{ div } \text{ten\_pow}[dd]))$ ; divide_scaled  $\leftarrow sign * q$ ;
end;

function round_xn_over_d( $x : \text{scaled}; n, d : \text{integer}$ ): scaled;
  var positive: boolean; { was  $x \geq 0$ ? }
   $t, u, v$ : nonnegative_integer; { intermediate quantities }
  begin if  $x \geq 0$  then positive  $\leftarrow true$ 
  else begin negate( $x$ ); positive  $\leftarrow false$ ;
  end;
   $t \leftarrow (x \text{ mod } '100000) * n$ ;  $u \leftarrow (x \text{ div } '100000) * n + (t \text{ div } '100000)$ ;
   $v \leftarrow (u \text{ mod } d) * '100000 + (t \text{ mod } '100000)$ ;
  if  $u \text{ div } d \geq '100000$  then arith_error  $\leftarrow true$ 
  else  $u \leftarrow '100000 * (u \text{ div } d) + (v \text{ div } d)$ ;
   $v \leftarrow v \text{ mod } d$ ;
  if  $2 * v \geq d$  then incr( $u$ );
  if positive then round_xn_over_d  $\leftarrow u$ 
  else round_xn_over_d  $\leftarrow -u$ ;
end;

```

690. Next subroutines are needed for controlling spacing in PDF page description. For a given character c from a font f , the procedure *adv_char_width* advances *pdf_h* by about the amount w , which is the character width. But we cannot simply add w to *pdf_h*. Instead we have to bring the required shift into the same raster, on which also the */Widths* array values, as they appear in the PDF file, are based. The *scaled_out* value is the w value moved into this raster. The */Widths* values are used by the PDF reader independently to update its positions. So one has to be sure, that calculations are properly synchronized. Currently the */Widths* array values are output with one digit after the decimal point, therefore the raster on which *adv_char_width* is operating is $1/10000$ of the *pdf_font_size*.

For PK fonts things are more complicated, as we have to deal with scaling bitmaps as well.

```

procedure adv_char_width( $f$  : internal_font_number;  $c$  : eight_bits);
    { update pdf_h by character width  $w$  from font  $f$  }
    var  $w, s\_out$  : scaled;  $s$  : integer;
    begin  $w \leftarrow \text{char\_width}(f)(\text{char\_info}(f)(c))$ ;
    if isscalable( $f$ ) then
        begin if pdf_cur_Tm_a = 0 then
            begin call_func(divide_scaled( $w, \text{pdf\_font\_size}[f], 4$ )); pdf_delta_h  $\leftarrow$  pdf_delta_h + scaled_out;
            end
        else begin  $s \leftarrow \text{divide\_scaled}(\text{round\_xn\_over\_d}(w, 1000, 1000 + \text{pdf\_cur\_Tm\_a}), \text{pdf\_font\_size}[f], 4)$ ;
             $s\_out \leftarrow \text{round\_xn\_over\_d}(\text{round\_xn\_over\_d}(\text{pdf\_font\_size}[f], \text{abs}(s), 10000), 1000 + \text{pdf\_cur\_Tm\_a}, 1000)$ ;
            if  $s < 0$  then  $s\_out \leftarrow -s\_out$ ;
            pdf_delta_h  $\leftarrow$  pdf_delta_h + s_out;
            end;
        end
    else pdf_delta_h  $\leftarrow$  pdf_delta_h + get_pk_char_width( $f, w$ );
    end;

procedure pdf_print_real( $m, d$  : integer); { print  $m/10^d$  as real }
    begin if  $m < 0$  then
        begin pdf_out("-");  $m \leftarrow -m$ ;
        end;
    pdf_print_int( $m \text{ div } \text{ten\_pow}[d]$ );  $m \leftarrow m \bmod \text{ten\_pow}[d]$ ;
    if  $m > 0$  then
        begin pdf_out("."); decr( $d$ );
        while  $m < \text{ten\_pow}[d]$  do
            begin pdf_out("0"); decr( $d$ );
            end;
        while  $m \bmod 10 = 0$  do  $m \leftarrow m \text{ div } 10$ ;
        pdf_print_int( $m$ );
        end;
    end;

procedure pdf_print_bp( $s$  : scaled); { print scaled as bp }
    begin pdf_print_real(divide_scaled( $s, \text{one\_hundred\_bp}, \text{fixed\_decimal\_digits} + 2$ ), fixed\_decimal\_digits);
    end;

procedure pdf_print_mag_bp( $s$  : scaled); { take mag into account }
    begin prepare_mag;
    if  $\text{mag} \neq 1000$  then  $s \leftarrow \text{round\_xn\_over\_d}(s, \text{mag}, 1000)$ ;
    pdf_print_bp( $s$ );
    end;

```

691. PDF page description.

```

define pdf_x(#)  $\equiv ((\textit{\#}) - \textit{pdf\_origin\_h})$  { convert x-coordinate from DVI to PDF }
define pdf_y(#)  $\equiv (\textit{pdf\_origin\_v} - (\textit{\#}))$  { convert y-coordinate from DVI to PDF }
define dvi_x(#)  $\equiv ((\textit{\#}) + \textit{pdf\_origin\_h})$  { convert x-coordinate from PDF to DVI }
define dvi_y(#)  $\equiv (\textit{pdf\_origin\_v} - (\textit{\#}))$  { convert y-coordinate from PDF to DVI }

⟨Global variables 13⟩ +=
pdf_f: internal_font_number; { the current font in PDF output page }
pdf_h: scaled; { current horizontal coordinate in PDF output page }
pdf_v: scaled; { current vertical coordinate in PDF output page }
pdf_tj_start_h: scaled; { horizontal coordinate in PDF output page just before TJ array start }
cur_delta_h: scaled; { horizontal cur_h offset from pdf_tj_start_h }
pdf_delta_h: scaled; { horizontal offset from pdf_tj_start_h }
pdf_origin_h: scaled; { current horizontal origin in PDF output page }
pdf_origin_v: scaled; { current vertical origin in PDF output page }
pdf_doing_string: boolean; { we are writing string to PDF file? }
pdf_doing_text: boolean; { we are writing text section to PDF file? }
min_bp_val: scaled;
min_font_val: scaled; { (TJ array system) }
fixed_pk_resolution: integer;
fixed_decimal_digits: integer;
fixed_gen_tounicode: integer;
fixed_inclusion_copy_font: integer;
pk_scale_factor: integer;
pdf_output_option: integer;
pdf_output_value: integer;
pdf_draftmode_option: integer;
pdf_draftmode_value: integer;
pdf_cur_Tm_a: integer; { a value of the current text matrix, i.e., the current horizontal scaling factor }
pdf_last_f: internal_font_number; { last font in PDF output page }
pdf_last_fs: internal_font_number; { last font size in PDF output page }
pdf_dummy_font: internal_font_number; { font used to insert artificial interword spaces }

```

692. Following procedures implement low-level subroutines to convert T_EX internal structures to PDF page description.

```

procedure pdf_set_origin(h, v : scaled); { set the origin to h, v }
  begin if (abs(h - pdf_origin_h) ≥ min_bp_val)  $\vee$  (abs(v - pdf_origin_v) ≥ min_bp_val) then
    begin pdf_print("1_0_0_1"); pdf_print_bp(h - pdf_origin_h);
      pdf_origin_h  $\leftarrow$  pdf_origin_h + scaled_out; pdf_out(""); pdf_print_bp(pdf_origin_v - v);
      pdf_origin_v  $\leftarrow$  pdf_origin_v - scaled_out; pdf_print_ln("_cm");
    end;
    pdf_h  $\leftarrow$  pdf_origin_h; pdf_tj_start_h  $\leftarrow$  pdf_h; pdf_v  $\leftarrow$  pdf_origin_v;
  end;

procedure pdf_set_origin_temp(h, v : scaled); { set the origin to h, v inside group }
  begin if (abs(h - pdf_origin_h) ≥ min_bp_val)  $\vee$  (abs(v - pdf_origin_v) ≥ min_bp_val) then
    begin pdf_print("1_0_0_1"); pdf_print_bp(h - pdf_origin_h); pdf_out("");
      pdf_print_bp(pdf_origin_v - v); pdf_print_ln("_cm");
    end;
  end;

procedure pdf_end_string; { end the current string }
  begin if pdf_doing_string then
    begin pdf_print(")]TJ"); pdf_doing_string  $\leftarrow$  false;
    end;
  end;

procedure pdf_end_string_nl; { end the current string, with new-line }
  begin if pdf_doing_string then
    begin pdf_print_ln(")]TJ"); pdf_doing_string  $\leftarrow$  false;
    end;
  end;

procedure pdf_set_textmatrix(v, v_out : scaled; f : internal_font_number);
  { set the next starting point to cur_h, cur_v }
  var pdf_new_Tm_a: integer; { a value of the new text matrix }
  begin pdf_out("");
  if f = pdf_f then pdf_new_Tm_a  $\leftarrow$  pdf_cur_Tm_a
  else if  $\neg$ pdf_font_auto_expand[f] then pdf_new_Tm_a  $\leftarrow$  0
    else pdf_new_Tm_a  $\leftarrow$  pdf_font_expand_ratio[f];
  if (pdf_new_Tm_a  $\neq$  0)  $\vee$  ((pdf_new_Tm_a = 0)  $\wedge$  (pdf_cur_Tm_a  $\neq$  0)) then
    begin pdf_print_real(1000 + pdf_new_Tm_a, 3); pdf_print("_0_0_1");
      pdf_print_bp(cur_h - pdf_origin_h); pdf_h  $\leftarrow$  pdf_origin_h + scaled_out; pdf_out("");
      pdf_print_bp(pdf_origin_v - cur_v); pdf_v  $\leftarrow$  pdf_origin_v - scaled_out; pdf_print("_Tm");
      pdf_cur_Tm_a  $\leftarrow$  pdf_new_Tm_a; pdfassert(pdf_cur_Tm_a > -1000);
    end
  else begin pdf_print_bp(cur_h - pdf_tj_start_h); { works only for unexpanded fonts }
    pdf_h  $\leftarrow$  pdf_tj_start_h + scaled_out; pdf_out(""); pdf_print_real(v, fixed_decimal_digits);
    { use v and v_out to avoid duplicate calculation }
    pdf_v  $\leftarrow$  pdf_v - v_out; pdf_print("_Td");
  end;
  pdf_tj_start_h  $\leftarrow$  pdf_h; pdf_delta_h  $\leftarrow$  0;
end;

procedure pdf_use_font(f : internal_font_number; fontnum : integer);
  { mark f as a used font; set font_used[f], pdf_font_size[f] and pdf_font_num[f] }
  begin call_func(divide_scaled(font_size[f], one_hundred_bp, 6)); pdf_font_size[f]  $\leftarrow$  scaled_out;
  font_used[f]  $\leftarrow$  true; pdfassert((fontnum > 0)  $\vee$  ((fontnum < 0)  $\wedge$  (pdf_font_num[-fontnum] > 0)));
  pdf_font_num[f]  $\leftarrow$  fontnum;
  if pdf_move_chars > 0 then

```

```
begin pdf_warning(0, "Primitive_\pdfmovechars_is_obsolete.", true, true); pdf_move_chars ← 0;  
    { warn only once }  
end;  
end;
```

693. To set PDF font we need to find out fonts with the same name, because T_EX can load the same font several times for various sizes. For such fonts we define only one font resource. The array *pdf_font_num* holds the object number of font resource. A negative value of an entry of *pdf_font_num* indicates that the corresponding font shares the font resource with the font.

```

define pdf_print_resname_prefix  $\equiv$ 
  if pdf_resname_prefix  $\neq$  0 then pdf_print(pdf_resname_prefix)

procedure pdf_init_font(f : internal_font_number); { create a font object }
  var k, b: internal_font_number; i: integer;
  begin pdf_assert( $\neg$ font_used[f]); { if f is auto expanded then ensure the base font is initialized }
  if pdf_font_auto_expand[f]  $\wedge$  (pdf_font_blink[f]  $\neq$  null_font) then
    begin b  $\leftarrow$  pdf_font_blink[f];
    if  $\neg$ isscalable(b) then
      pdf_error("font_expansion", "auto_expansion_is_only_possible_with_scalable_fonts");
    if  $\neg$ font_used[b] then pdf_init_font(b);
    pdf_font_map[f]  $\leftarrow$  pdf_font_map[b];
  end; { check whether f can share the font object with some k: we have 2 cases here: 1) f and k have
    the same tfm name (so they have been loaded at different sizes, e.g., 'cmr10' and 'cmr10 at 11pt');
    2) f has been auto expanded from k }
  if isscalable(f) then
    begin i  $\leftarrow$  head_tab[obj_type_font];
    while i  $\neq$  0 do
      begin k  $\leftarrow$  obj_info(i);
      if isscalable(k)  $\wedge$  (pdf_font_map[k] = pdf_font_map[f]  $\wedge$  (str_eq_str(font_name[k],
        font_name[f]  $\vee$  (pdf_font_auto_expand[f]  $\wedge$  (pdf_font_blink[f]  $\neq$ 
        null_font)  $\wedge$  str_eq_str(font_name[k], font_name[pdf_font_blink[f]]))) then
        begin pdf_assert(pdf_font_num[k]  $\neq$  0);
        if pdf_font_num[k] < 0 then pdf_use_font(f, pdf_font_num[k])
        else pdf_use_font(f, -k);
        return;
      end;
      i  $\leftarrow$  obj_link(i);
    end;
    end; { create a new font object for f }
  pdf_create_obj(obj_type_font, f); pdf_use_font(f, obj_ptr);
end;

procedure pdf_init_font_cur_val;
  begin pdf_init_font(cur_val);
end;

procedure pdf_set_font(f : internal_font_number); { set the actual font on PDF page }
  label found, found1;
  var p: pointer; k: internal_font_number;
  begin if  $\neg$ font_used[f] then pdf_init_font(f);
  set_ff(f); { set ff to the tfm number of the font sharing the font object with f; ff is either f or some
    font with the same tfm name at different size and/or expansion }
  k  $\leftarrow$  ff; p  $\leftarrow$  pdf_font_list;
  while p  $\neq$  null do
    begin set_ff(info(p));
    if ff = k then goto found;
    p  $\leftarrow$  link(p);
  end;
  pdf_append_list(f)(pdf_font_list); { f not found in pdf_font_list, append it now }
found: if (k = pdf_last_f)  $\wedge$  (font_size[f] = pdf_last_fs) then return;

```

```

pdf_print("/F"); pdf_print_int(k); pdf_print_resname_prefix; pdf_out(" ");
pdf_print_real(divide_scaled(font_size[f], one_hundred_bp, 6), 4); pdf_print("_Tf"); pdf_last_f ← k;
pdf_last_fs ← font_size[f];
end;
procedure pdf_begin_text; { begin a text section }
begin pdf_set_origin(0, cur_page_height); pdf_print_ln("BT"); pdf_doing_text ← true; pdf_f ← null_font;
pdf_last_f ← null_font; pdf_last_fs ← 0; pdf_doing_string ← false; pdf_cur_Tm_a ← 0;
end;
procedure pdf_read_dummy_font;
begin if pdf_dummy_font = null_font then
  begin pdf_dummy_font ← read_font_info(null_cs, "dummy-space", "", one_bp);
  pdf_mark_char(pdf_dummy_font, 32);
  end;
end;
procedure pdf_insert_interword_space; { insert an artificial interword space }
begin pdf_read_dummy_font; pdf_set_font(pdf_dummy_font); pdf_print("␣Tj");
end;
procedure pdf_begin_string(f : internal_font_number); { begin to draw a string }
var s_out, v, v_out : scaled; s : integer; must_end_string : boolean; { must we end the current string? }
    must_insert_space : boolean; { must we insert an interword space? }
begin if ¬pdf_doing_text then pdf_begin_text;
if f ≠ pdf_f then
  begin pdf_end_string; pdf_set_font(f);
  end;
if pdf_cur_Tm_a = 0 then
  begin s ← divide_scaled(cur_h - (pdf_tj_start_h + pdf_delta_h), pdf_font_size[f], 3); s_out ← scaled_out;
  end
else begin s ← divide_scaled(round_xn_over_d(cur_h - (pdf_tj_start_h + pdf_delta_h), 1000,
    1000 + pdf_cur_Tm_a), pdf_font_size[f], 3);
  if abs(s) < '100000 then
    begin s_out ← round_xn_over_d(round_xn_over_d(pdf_font_size[f], abs(s), 1000),
      1000 + pdf_cur_Tm_a, 1000);
    if s < 0 then s_out ← -s_out;
    end; { no need to calculate s_out when abs(s) ≥ '100000, since the text matrix will be reset below }
  end;
if abs(cur_v - pdf_v) ≥ min_bp_val then
  begin v ← divide_scaled(pdf_v - cur_v, one_hundred_bp, fixed_decimal_digits + 2); v_out ← scaled_out;
  end
else begin v ← 0; v_out ← 0;
  end;
  must_insert_space ← false; must_end_string ← false; @{print_nl("s_out␣=␣"); print_scaled(s_out);
  @}@{print_nl("space(f)␣=␣"); print_scaled(space(f)); @}@{print_nl("space_shrink(f)␣=␣");
  print_scaled(space_shrink(f)); @}@{print_nl("x_height(f)␣=␣"); print_scaled(x_height(f));
  @}@{print_nl("v␣=␣"); print_scaled(v); @}@{print_nl("v_out␣=␣"); print_scaled(v_out); @}
  if gen_faked_interword_space ∧ pdf_doing_string ∧ ((abs(v_out) > 2 * x_height(f)) ∨ (s_out >
    space(f) - space_shrink(f)) ∨ ((f ≠ pdf_f) ∧ (v = 0))) then
    begin must_insert_space ← true;
    end;
if (f ≠ pdf_f) ∨ (v ≠ 0) ∨ (abs(s) ≥ '100000) ∨ must_insert_space then
  begin must_end_string ← true;
  end;
if must_end_string then

```

```

begin pdf_end_string;
if must_insert_space then
  begin pdf_insert_interword_space; { this will change pdf_f }
  pdf_set_font(f);
  end;
  pdf_set_textmatrix(v, v_out, f); pdf_f ← f; s ← 0;
end;
if ¬pdf_doing_string then
  begin pdf_print("␣");
  if s = 0 then pdf_out("(");
  end;
if s ≠ 0 then
  begin if pdf_doing_string then pdf_out(")");
  pdf_print_int(-s); pdf_out("("); pdf_delta_h ← pdf_delta_h + s_out;
  end;
  pdf_doing_string ← true;
end;
procedure pdf_insert_fake_space;
  var s: integer; { to save gen_faked_interword_space }
  begin s ← gen_faked_interword_space; gen_faked_interword_space ← 0;
  { to prevent inserting another fake space in pdf_begin_string }
  pdf_read_dummy_font; pdf_begin_string(pdf_dummy_font); pdf_print("␣"); pdf_end_string_nl;
  gen_faked_interword_space ← s;
  end;
procedure pdf_end_text; { end a text section }
  begin if pdf_doing_text then
    begin pdf_end_string_nl; pdf_print_ln("ET"); pdf_doing_text ← false;
    end;
  end;
procedure pdf_set_rule(x, y, w, h : scaled); { draw a rule }
  begin pdf_end_text; pdf_print_ln("q");
  if h ≤ one_bp then
    begin pdf_set_origin_temp(x, y - (h + 1)/2); pdf_print("[␣0␣d␣0␣J␣"); pdf_print_bp(h);
    pdf_print("␣w␣0␣0␣m␣"); pdf_print_bp(w); pdf_print_ln("␣0␣1␣S");
    end
  else if w ≤ one_bp then
    begin pdf_set_origin_temp(x + (w + 1)/2, y); pdf_print("[␣0␣d␣0␣J␣"); pdf_print_bp(w);
    pdf_print("␣w␣0␣0␣m␣0␣"); pdf_print_bp(h); pdf_print_ln("␣1␣S");
    end
  else begin pdf_set_origin_temp(x, y); pdf_print("0␣0␣"); pdf_print_bp(w); pdf_out("␣");
  pdf_print_bp(h); pdf_print_ln("␣re␣f");
  end;
  pdf_print_ln("Q");
  end;
procedure pdf_rectangle(left, top, right, bottom : scaled); { output a rectangle specification to PDF file }
  begin prepare_mag; pdf_print("/Rect␣"); pdf_print_mag_bp(pdf_x(left)); pdf_out("␣");
  pdf_print_mag_bp(pdf_y(bottom)); pdf_out("␣"); pdf_print_mag_bp(pdf_x(right)); pdf_out("␣");
  pdf_print_mag_bp(pdf_y(top)); pdf_print_ln("]");
  end; { Prints first len characters of string s (if it's that long). There must be a better way to print a
  substring? }
procedure slow_print_substr(s, max_len : integer);
  var j: pool_pointer; { current character code position }

```



```

begin if ( $s \geq \text{str\_ptr}$ )  $\vee$  ( $s < 256$ ) then  $\text{print}(s)$ 
else begin  $j \leftarrow \text{str\_start}[s]$ ;
  while ( $j < \text{str\_start}[s + 1]$ )  $\wedge$  ( $j \leq \text{str\_start}[s] + \text{max\_len}$ ) do
    begin  $\text{print}(\text{so}(\text{str\_pool}[j]))$ ;  $\text{incr}(j)$ ;
    end;
  end;
if  $j < \text{str\_start}[s + 1]$  then  $\text{print}(\dots)$ ; { indicate truncation }
end;
procedure  $\text{literal}(s : \text{str\_number}; \text{literal\_mode} : \text{integer}; \text{warn} : \text{boolean})$ ;
var  $j$ :  $\text{pool\_pointer}$ ; { current character code position }
begin  $j \leftarrow \text{str\_start}[s]$ ;
if  $\text{literal\_mode} = \text{scan\_special}$  then
  begin if  $\neg(\text{str\_in\_str}(s, \text{"PDF:"}, 0) \vee \text{str\_in\_str}(s, \text{"pdf:"}, 0))$  then
    begin if  $\text{warn} \wedge \neg(\text{str\_in\_str}(s, \text{"SRC:"}, 0) \vee \text{str\_in\_str}(s, \text{"src:"}, 0) \vee (\text{length}(s) = 0))$  then
      begin  $\text{print\_nl}(\text{"Non-PDF\_special\_ignored!"})$ ;  $\text{print\_nl}(\text{"<special>"})$ ;
       $\text{slow\_print\_substr}(s, 64)$ ; { length of printed line should be  $j=78$ ; good enough. }
       $\text{print\_ln}$ ;
      end;
    return;
    end;
     $j \leftarrow j + \text{length}(\text{"PDF:"})$ ;
    if  $\text{str\_in\_str}(s, \text{"direct:"}, \text{length}(\text{"PDF:"}))$  then
      begin  $j \leftarrow j + \text{length}(\text{"direct:"})$ ;  $\text{literal\_mode} \leftarrow \text{direct\_always}$ ;
      end
    else if  $\text{str\_in\_str}(s, \text{"page:"}, \text{length}(\text{"PDF:"}))$  then
      begin  $j \leftarrow j + \text{length}(\text{"page:"})$ ;  $\text{literal\_mode} \leftarrow \text{direct\_page}$ ;
      end
    else  $\text{literal\_mode} \leftarrow \text{set\_origin}$ ;
  end;
case  $\text{literal\_mode}$  of
   $\text{set\_origin}$ : begin  $\text{pdf\_end\_text}$ ;  $\text{pdf\_set\_origin}(\text{cur\_h}, \text{cur\_v})$ ;
    end;
   $\text{direct\_page}$ :  $\text{pdf\_end\_text}$ ;
   $\text{direct\_always}$ :  $\text{pdf\_end\_string\_nl}$ ;
  othercases  $\text{confusion}(\text{"literal1"})$ 
endcases;
while  $j < \text{str\_start}[s + 1]$  do
  begin  $\text{pdf\_out}(\text{str\_pool}[j])$ ;  $\text{incr}(j)$ ;
  end;
 $\text{pdf\_print\_nl}$ ;
end;

```

694. The cross-reference table. The cross-reference table *obj_tab* is an array of *obj_tab_size* of *obj_entry*. Each entry contains five integer fields and represents an object in PDF file whose object number is the index of this entry in *obj_tab*. Objects in *obj_tab* maybe linked into list; objects in such a linked list have the same type.

⟨Types in the outer block 18⟩ +≡
obj_entry = **record** *int0, int1: integer*;
 int2: longinteger;
 int3, int4: integer;
 end;

695. The first field contains information representing identifier of this object. It is usually a number for most of object types, but it may be a string number for named destination or named thread.

The second field of *obj_entry* contains link to the next object in *obj_tab* if this object is linked in a list.

The third field holds the byte offset of the object in the output PDF file, or its byte offset within an object stream. As long as the object is not written, this field is used for flags about the write status of the object; then it has a negative value.

The fourth field holds the object number of the object stream, into which the object is included.

The last field usually represents the pointer to some auxiliary data structure depending on the object type; however it may be used as a counter as well.

```

define obj_info(#)  $\equiv$  obj_tab[#].int0  { information representing identifier of this object }
define obj_link(#)  $\equiv$  obj_tab[#].int1  { link to the next entry in linked list }
define obj_offset(#)  $\equiv$  obj_tab[#].int2  { negative (flags), or byte offset for this object in PDF output
      file, or object stream number for this object }
define obj_os_idx(#)  $\equiv$  obj_tab[#].int3  { index of this object in object stream }
define obj_aux(#)  $\equiv$  obj_tab[#].int4  { auxiliary pointer }
define set_obj_fresh(#)  $\equiv$  obj_offset(#)  $\leftarrow$  -2
define set_obj_scheduled(#)  $\equiv$ 
      if obj_offset(#) = -2 then obj_offset(#)  $\leftarrow$  -1
define is_obj_scheduled(#)  $\equiv$  (obj_offset(#) > -2)
define is_obj_written(#)  $\equiv$  (obj_offset(#) > -1)

      { types of objects }
define obj_type_others  $\equiv$  0  { objects which are not linked in any list }
define obj_type_page  $\equiv$  1  { index of linked list of Page objects }
define obj_type_pages  $\equiv$  2  { index of linked list of Pages objects }
define obj_type_font  $\equiv$  3  { index of linked list of Fonts objects }
define obj_type_outline  $\equiv$  4  { index of linked list of outline objects }
define obj_type_dest  $\equiv$  5  { index of linked list of destination objects }
define obj_type_obj  $\equiv$  6  { index of linked list of raw objects }
define obj_type_xform  $\equiv$  7  { index of linked list of XObject forms }
define obj_type_ximage  $\equiv$  8  { index of linked list of XObject image }
define obj_type_thread  $\equiv$  9  { index of linked list of num article threads }
define head_tab_max  $\equiv$  obj_type_thread  { max index of head_tab }

      { max number of kids for balanced trees }
define pages_tree_kids_max  $\equiv$  6  { max number of kids of Pages tree node }
define name_tree_kids_max  $\equiv$  6  { max number of kids of node of name tree for name destinations }

      { when a whatsit node representing annotation is created, words 1 .. 3 are width, height and
        depth of this annotation; after shipping out words 1 .. 4 are rectangle specification of
        annotation. For whatsit node representing destination pdf_left and pdf_top are used for some
        types of destinations }

      { coordinates of destinations/threads/annotations (in whatsit node) }
define pdf_left(#)  $\equiv$  mem[# + 1].sc
define pdf_top(#)  $\equiv$  mem[# + 2].sc
define pdf_right(#)  $\equiv$  mem[# + 3].sc
define pdf_bottom(#)  $\equiv$  mem[# + 4].sc

      { dimension of destinations/threads/annotations (in whatsit node) }
define pdf_width(#)  $\equiv$  mem[# + 1].sc
define pdf_height(#)  $\equiv$  mem[# + 2].sc
define pdf_depth(#)  $\equiv$  mem[# + 3].sc

      { data structure for \pdfliteral }
define pdf_literal_data(#)  $\equiv$  link(# + 1)  { data }

```

```

define pdf_literal_mode(#)  $\equiv$  info(# + 1)
    { mode of resetting the text matrix while writing data to the page stream }
    { modes of setting the current transformation matrix (CTM) }
define set_origin  $\equiv$  0    { end text (ET) if needed, set CTM to current point }
define direct_page  $\equiv$  1    { end text (ET) if needed, but don't change the CTM }
define direct_always  $\equiv$  2  { don't end text, don't change the CTM }
define scan_special  $\equiv$  3   { look into special text }

    { data structure for \pdfcolorstack }
define pdf_colorstack_node_size  $\equiv$  3
define pdf_colorstack_setter_node_size  $\equiv$  3
define pdf_colorstack_getter_node_size  $\equiv$  2
define pdf_colorstack_stack(#)  $\equiv$  link(# + 1)  { stack number }
define pdf_colorstack_cmd(#)  $\equiv$  info(# + 1)  { command: set, push, pop, current }
define pdf_colorstack_data(#)  $\equiv$  link(# + 2)  { data }

    { color stack commands }
define colorstack_set  $\equiv$  0
define colorstack_push  $\equiv$  1
define colorstack_data  $\equiv$  1  { last value where data field is set }
define colorstack_pop  $\equiv$  2
define colorstack_current  $\equiv$  3

    { data structure for \pdfsetmatrix }
define pdf_setmatrix_node_size  $\equiv$  2
define pdf_setmatrix_data(#)  $\equiv$  link(# + 1)  { data }

    { data structure for \pdfsave }
define pdf_save_node_size  $\equiv$  2

    { data structure for \pdfrestore }
define pdf_restore_node_size  $\equiv$  2

    { data structure for \pdfobj and \pdfrefobj }
define pdf_refobj_node_size  $\equiv$  2  { size of whatsit node representing the raw object }
define pdf_obj_objnum(#)  $\equiv$  info(# + 1)  { number of the raw object }
define obj_data_ptr  $\equiv$  obj_aux  { pointer to pdf_mem }
define pdfmem_obj_size  $\equiv$  4  { size of memory in pdf_mem which obj_data_ptr holds }
define obj_obj_data(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 0]  { object data }
define obj_obj_is_stream(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 1]
    { will this object be written as a stream instead of a dictionary? }
define obj_obj_stream_attr(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 2]
    { additional object attributes for streams }
define obj_obj_is_file(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 3]  { data should be read from an external file? }

    { data structure for \pdfxform and \pdfrefxform }
define pdf_refxform_node_size  $\equiv$  5  { size of whatsit node for xform; words 1..3 are form dimensions }
define pdf_xform_objnum(#)  $\equiv$  info(# + 4)  { object number }
define pdfmem_xform_size  $\equiv$  6  { size of memory in pdf_mem which obj_data_ptr holds }
define obj_xform_width(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 0]
define obj_xform_height(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 1]
define obj_xform_depth(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 2]
define obj_xform_box(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 3]
    { this field holds pointer to the corresponding box }
define obj_xform_attr(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 4]  { additional xform attributes }
define obj_xform_resources(#)  $\equiv$  pdf_mem[obj_data_ptr(#) + 5]  { additional xform Resources }

    { data structure for \pdfximage and \pdfrefximage }

```

```

define pdf_refximage_node_size ≡ 5 { size of whatsit node for ximage; words 1..3 are image dimensions }
define pdf_ximage_objnum( # ) ≡ info( # + 4 ) { object number }
define pdfmem_ximage_size ≡ 5 { size of memory in pdf_mem which obj_data_ptr holds }
define obj_ximage_width( # ) ≡ pdf_mem[ obj_data_ptr( # ) + 0 ]
define obj_ximage_height( # ) ≡ pdf_mem[ obj_data_ptr( # ) + 1 ]
define obj_ximage_depth( # ) ≡ pdf_mem[ obj_data_ptr( # ) + 2 ]
define obj_ximage_attr( # ) ≡ pdf_mem[ obj_data_ptr( # ) + 3 ] { additional ximage attributes }
define obj_ximage_data( # ) ≡ pdf_mem[ obj_data_ptr( # ) + 4 ] { pointer to image data }

{ data structure of annotations; words 1..4 represent the coordinates of the annotation }
define obj_annot_ptr ≡ obj_aux { pointer to corresponding whatsit node }
define pdf_annot_node_size ≡ 7 { size of whatsit node representing annotation }
define pdf_annot_data( # ) ≡ info( # + 5 ) { raw data of general annotations }
define pdf_link_attr( # ) ≡ info( # + 5 ) { attributes of link annotations }
define pdf_link_action( # ) ≡ link( # + 5 ) { pointer to action structure }
define pdf_annot_objnum( # ) ≡ mem[ # + 6 ].int { object number of corresponding object }
define pdf_link_objnum( # ) ≡ mem[ # + 6 ].int { object number of corresponding object }

{ types of actions }
define pdf_action_page ≡ 0 { GoTo action }
define pdf_action_goto ≡ 1 { GoTo action }
define pdf_action_thread ≡ 2 { Thread action }
define pdf_action_user ≡ 3 { user-defined action }

{ data structure of actions }
define pdf_action_size ≡ 3 { size of action structure in mem }
define pdf_action_type ≡ type { action type }
define pdf_action_named_id ≡ subtype { identifier is type of name }
define pdf_action_id ≡ link { destination/thread name identifier }
define pdf_action_file( # ) ≡ info( # + 1 ) { file name for external action }
define pdf_action_new_window( # ) ≡ link( # + 1 ) { open a new window? }
define pdf_action_page_tokens( # ) ≡ info( # + 2 ) { specification of GoTo page action }
define pdf_action_user_tokens( # ) ≡ info( # + 2 ) { user-defined action string }
define pdf_action_refcount( # ) ≡ link( # + 2 ) { counter of references to this action }

{ data structure of outlines; it's not able to write out outline entries before all outline entries
are defined, so memory allocated for outline entries can't not be deallocated and will stay in
memory. For this reason we will store data of outline entries in pdf_mem instead of mem }
define pdfmem_outline_size ≡ 8 { size of memory in pdf_mem which obj_outline_ptr points to }
define obj_outline_count ≡ obj_info { count of all opened children }
define obj_outline_ptr ≡ obj_aux { pointer to pdf_mem }
define obj_outline_title( # ) ≡ pdf_mem[ obj_outline_ptr( # ) ]
define obj_outline_parent( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 1 ]
define obj_outline_prev( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 2 ]
define obj_outline_next( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 3 ]
define obj_outline_first( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 4 ]
define obj_outline_last( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 5 ]
define obj_outline_action_objnum( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 6 ] { object number of action }
define obj_outline_attr( # ) ≡ pdf_mem[ obj_outline_ptr( # ) + 7 ]

{ types of destinations }
define pdf_dest_xyz ≡ 0
define pdf_dest_fit ≡ 1
define pdf_dest_fith ≡ 2
define pdf_dest_fitv ≡ 3
define pdf_dest_fitb ≡ 4

```

```

define pdf_dest_fitbh  $\equiv$  5
define pdf_dest_fitbv  $\equiv$  6
define pdf_dest_fitr  $\equiv$  7
    { data structure of destinations }
define obj_dest_ptr  $\equiv$  obj_aux { pointer to pdf_dest_node }
define pdf_dest_node_size  $\equiv$  7
    { size of whatsit node for destination; words 1 .. 4 hold dest dimensions, word 6 identifier
      type, subtype and identifier of destination, word 6 the corresponding object number }
define pdf_dest_type( $\#$ )  $\equiv$  type( $\# + 5$ ) { type of destination }
define pdf_dest_named_id( $\#$ )  $\equiv$  subtype( $\# + 5$ ) { is named identifier? }
define pdf_dest_id( $\#$ )  $\equiv$  link( $\# + 5$ ) { destination identifier }
define pdf_dest_xyz_zoom( $\#$ )  $\equiv$  info( $\# + 6$ ) { zoom factor for destxyz destination }
define pdf_dest_objnum( $\#$ )  $\equiv$  link( $\# + 6$ ) { object number of corresponding object }
    { data structure of threads; words 1..4 represent the coordinates of the corners }
define pdf_thread_node_size  $\equiv$  7
define pdf_thread_named_id( $\#$ )  $\equiv$  subtype( $\# + 5$ ) { is a named identifier }
define pdf_thread_id( $\#$ )  $\equiv$  link( $\# + 5$ ) { thread identifier }
define pdf_thread_attr( $\#$ )  $\equiv$  info( $\# + 6$ ) { attributes of thread }
define obj_thread_first  $\equiv$  obj_aux { pointer to the first bead }
    { data structure of beads }
define pdfmem_bead_size  $\equiv$  5 { size of memory in pdf_mem which obj_bead_ptr points to }
define obj_bead_ptr  $\equiv$  obj_aux { pointer to pdf_mem }
define obj_bead_rect( $\#$ )  $\equiv$  pdf_mem[obj_bead_ptr( $\#$ )]
define obj_bead_page( $\#$ )  $\equiv$  pdf_mem[obj_bead_ptr( $\#$ ) + 1]
define obj_bead_next( $\#$ )  $\equiv$  pdf_mem[obj_bead_ptr( $\#$ ) + 2]
define obj_bead_prev( $\#$ )  $\equiv$  pdf_mem[obj_bead_ptr( $\#$ ) + 3]
define obj_bead_attr( $\#$ )  $\equiv$  pdf_mem[obj_bead_ptr( $\#$ ) + 4]
define obj_bead_data  $\equiv$  obj_bead_rect { pointer to the corresponding whatsit node; obj_bead_rect is
    needed only when the bead rectangle has been written out and after that obj_bead_data is not
    needed any more so we can use this field for both }
    { data structure of snap node }
define snap_node_size  $\equiv$  3
define snap_glue_ptr( $\#$ )  $\equiv$  info( $\# + 1$ )
define final_skip( $\#$ )  $\equiv$  mem[ $\# + 2$ ].sc { the amount to skip }
    { data structure of snap compensation node }
define snap_comp_ratio( $\#$ )  $\equiv$  mem[ $\# + 1$ ].int
< Constants in the outer block 11 > +=
inf_obj_tab_size = 1000; { min size of the cross-reference table for PDF output }
sup_obj_tab_size = 8388607; { max size of the cross-reference table for PDF output }
inf_dest_names_size = 1000; { min size of the destination names table for PDF output }
sup_dest_names_size = 500000; { max size of the destination names table for PDF output }
inf_pk_dpi = 72; { min PK pixel density value from texmf.cnf }
sup_pk_dpi = 8000; { max PK pixel density value from texmf.cnf }
pdf_objtype_max = head_tab_max;

```

696. \langle Global variables 13 $\rangle + \equiv$

obj_tab_size: integer;
obj_tab: \uparrow *obj_entry*;
head_tab: **array** [1 .. *head_tab_max*] **of** integer;
pages_tail: integer;
obj_ptr: integer; { user objects counter }
sys_obj_ptr: integer; { system objects counter, including object streams }
pdf_last_pages: integer; { pointer to most recently generated pages object }
pdf_last_page: integer; { pointer to most recently generated page object }
pdf_last_stream: integer; { pointer to most recently generated stream }
pdf_stream_length: longinteger; { length of most recently generated stream }
pdf_stream_length_offset: longinteger; { file offset of the last stream length }
pdf_seek_write_length: boolean; { flag whether to seek back and write /Length }
pdf_last_byte: eight_bits; { byte most recently written to PDF file; for **endstream** in new line }
pdf_append_list_arg: integer; { for use with *pdf_append_list* }
ff: integer; { for use with *set_ff* }
pdf_box_spec_media: integer;
pdf_box_spec_crop: integer;
pdf_box_spec_bleed: integer;
pdf_box_spec_trim: integer;
pdf_box_spec_art: integer;

697. \langle Set initial values of key variables 21 $\rangle + \equiv$

obj_ptr \leftarrow 0; *sys_obj_ptr* \leftarrow 0; *obj_tab_size* \leftarrow *inf_obj_tab_size*; { allocated size of *obj_tab* array }
dest_names_size \leftarrow *inf_dest_names_size*; { allocated size of *dest_names* array }
for *k* \leftarrow 1 **to** *head_tab_max* **do** *head_tab*[*k*] \leftarrow 0;
pdf_box_spec_media \leftarrow 1; *pdf_box_spec_crop* \leftarrow 2; *pdf_box_spec_bleed* \leftarrow 3; *pdf_box_spec_trim* \leftarrow 4;
pdf_box_spec_art \leftarrow 5; *pdf_dummy_font* \leftarrow *null_font*;

698. Here we implement subroutines for work with objects and related things. Some of them are used in former parts too, so we need to declare them forward.

```

define pdf_append_list_end(#)  $\equiv$  #  $\leftarrow$  append_ptr(#, pdf_append_list_arg);
end
define pdf_append_list(#)  $\equiv$ 
  begin pdf_append_list_arg  $\leftarrow$  #; pdf_append_list_end
define set_ff(#)  $\equiv$ 
  begin if pdf_font_num[#] < 0 then ff  $\leftarrow$  -pdf_font_num[#]
  else ff  $\leftarrow$  #;
  end

(Declare procedures that need to be declared forward for pdfTeX 686)  $\equiv$ 
procedure append_dest_name(s : str_number; n : integer);
  var a : integer;
  begin if pdf_dest_names_ptr = sup_dest_names_size then
    overflow("number_of_destination_names_(dest_names_size)", dest_names_size);
  if pdf_dest_names_ptr = dest_names_size then
    begin a  $\leftarrow$  0.2 * dest_names_size;
    if dest_names_size < sup_dest_names_size - a then dest_names_size  $\leftarrow$  dest_names_size + a
    else dest_names_size  $\leftarrow$  sup_dest_names_size;
    dest_names  $\leftarrow$  xrealloc_array(dest_names, dest_name_entry, dest_names_size);
    end;
  dest_names[pdf_dest_names_ptr].objname  $\leftarrow$  s; dest_names[pdf_dest_names_ptr].objnum  $\leftarrow$  n;
  incr(pdf_dest_names_ptr);
end;

procedure pdf_create_obj(t, i : integer); { create an object with type t and identifier i }
  label done;
  var a, p, q : integer;
  begin if sys_obj_ptr = sup_obj_tab_size then overflow("indirect_objects_table_size", obj_tab_size);
  if sys_obj_ptr = obj_tab_size then
    begin a  $\leftarrow$  0.2 * obj_tab_size;
    if obj_tab_size < sup_obj_tab_size - a then obj_tab_size  $\leftarrow$  obj_tab_size + a
    else obj_tab_size  $\leftarrow$  sup_obj_tab_size;
    obj_tab  $\leftarrow$  xrealloc_array(obj_tab, obj_entry, obj_tab_size);
    end;
  incr(sys_obj_ptr); obj_ptr  $\leftarrow$  sys_obj_ptr; obj_info(obj_ptr)  $\leftarrow$  i; set_obj_fresh(obj_ptr);
  obj_aux(obj_ptr)  $\leftarrow$  0; avl_put_obj(obj_ptr, t);
  if t = obj_type_page then
    begin p  $\leftarrow$  head_tab[t]; { find the right position to insert newly created object }
    if (p = 0)  $\vee$  (obj_info(p) < i) then
      begin obj_link(obj_ptr)  $\leftarrow$  p; head_tab[t]  $\leftarrow$  obj_ptr;
      end
    else begin while p  $\neq$  0 do
      begin if obj_info(p) < i then goto done;
      q  $\leftarrow$  p; p  $\leftarrow$  obj_link(p);
      end;
    done: obj_link(q)  $\leftarrow$  obj_ptr; obj_link(obj_ptr)  $\leftarrow$  p;
    end;
  end
else if t  $\neq$  obj_type_others then
  begin obj_link(obj_ptr)  $\leftarrow$  head_tab[t]; head_tab[t]  $\leftarrow$  obj_ptr;
  if (t = obj_type_dest)  $\wedge$  (i < 0) then append_dest_name(-obj_info(obj_ptr), obj_ptr);
  end;

```



```

end;
function pdf_new_objnum: integer; { create a new object and return its number }
begin pdf_create_obj(obj_type_others, 0); pdf_new_objnum ← obj_ptr;
end;
procedure pdf_os_switch(pdf_os : boolean); { switch between PDF stream and object stream mode }
begin if pdf_os ∧ pdf_os_enable then
  begin if ¬pdf_os_mode then
    begin { back up PDF stream variables }
      pdf_op_ptr ← pdf_ptr; pdf_ptr ← pdf_os_ptr; pdf_buf ← pdf_os_buf; pdf_buf_size ← pdf_os_buf_size;
      pdf_os_mode ← true; { switch to object stream }
    end;
  end
else begin if pdf_os_mode then
  begin { back up object stream variables }
    pdf_os_ptr ← pdf_ptr; pdf_ptr ← pdf_op_ptr; pdf_buf ← pdf_op_buf; pdf_buf_size ← pdf_op_buf_size;
    pdf_os_mode ← false; { switch to PDF stream }
  end;
end;
end;
procedure pdf_os_prepare_obj(i : integer; pdf_os_level : integer);
  { create new /ObjStm object if required, and set up cross reference info }
begin pdf_os_switch((pdf_os_level > 0) ∧ (fixed_pdf_objcompresslevel ≥ pdf_os_level));
if pdf_os_mode then
  begin if pdf_os_cur_objnum = 0 then
    begin pdf_os_cur_objnum ← pdf_new_objnum; decr(obj_ptr);
      { object stream is not accessible to user }
    incr(pdf_os_cntr); { only for statistics }
    pdf_os_objidx ← 0; pdf_ptr ← 0; { start fresh object stream }
    end
  else incr(pdf_os_objidx);
    obj_os_idx(i) ← pdf_os_objidx; obj_offset(i) ← pdf_os_cur_objnum; pdf_os_objnum[pdf_os_objidx] ← i;
    pdf_os_objoff[pdf_os_objidx] ← pdf_ptr;
    end
  else begin obj_offset(i) ← pdf_offset; obj_os_idx(i) ← -1; { mark it as not included in object stream }
  end;
end;
procedure pdf_begin_obj(i : integer; pdf_os_level : integer); { begin a PDF object }
begin check_pdfversion; pdf_os_prepare_obj(i, pdf_os_level);
if ¬pdf_os_mode then
  begin pdf_print_int(i); pdf_print_ln("␣0␣obj");
  end
else if pdf_compress_level = 0 then
  begin pdf_print("%␣"); { debugging help }
    pdf_print_int(i); pdf_print_ln("␣0␣obj");
  end;
end;
end;
procedure pdf_new_obj(t, i : integer; pdf_os : integer); { begin a new PDF object }
begin pdf_create_obj(t, i); pdf_begin_obj(obj_ptr, pdf_os);
end;
procedure pdf_end_obj; { end a PDF object }
begin if pdf_os_mode then
  begin if pdf_os_objidx = pdf_os_max_objs - 1 then pdf_os_write_objstream;

```

```

    end
  else pdf_print_ln("endobj"); { end a PDF object }
end;
procedure pdf_begin_dict(i : integer; pdf_os_level : integer); { begin a PDF dictionary object }
  begin check_pdfversion; pdf_os_prepare_obj(i, pdf_os_level);
  if ¬pdf_os_mode then
    begin pdf_print_int(i); pdf_print_ln("0obj");
    end
  else if pdf_compress_level = 0 then
    begin pdf_print("%"); { debugging help }
    pdf_print_int(i); pdf_print_ln("0obj");
    end;
  pdf_print_ln("<<");
  end;
procedure pdf_new_dict(t, i : integer; pdf_os : integer); { begin a new PDF dictionary object }
  begin pdf_create_obj(t, i); pdf_begin_dict(obj_ptr, pdf_os);
  end;
procedure pdf_end_dict; { end a PDF dictionary object }
  begin if pdf_os_mode then
    begin pdf_print_ln(">>");
    if pdf_os_objidx = pdf_os_max_objs - 1 then pdf_os_write_objstream;
    end
  else begin pdf_print_ln(">>"); pdf_print_ln("endobj");
  end;
end;

```

699. Write out an accumulated object stream. First the object number and byte offset pairs are generated and appended to the ready buffered object stream. By this the value of `/First` can be calculated. Then a new `/ObjStm` object is generated, and everything is copied to the PDF output buffer, where also compression is done. When calling this procedure, *pdf_os_mode* must be *true*.

⟨Declare procedures that need to be declared forward for pdfTeX 686⟩ +≡

```

procedure pdf_os_write_objstream;
  var i, j, p, q: pointer;
  begin if pdf_os_cur_objnum = 0 then { no object stream started }
    return;
  p ← pdf_ptr; i ← 0; j ← 0;
  while i ≤ pdf_os_objidx do
    begin { assemble object number and byte offset pairs }
      pdf_print_int(pdf_os_objnum[i]); pdf_print(" "); pdf_print_int(pdf_os_objoff[i]);
    if j = 9 then
      begin { print out in groups of ten for better readability }
        pdf_out(pdf_new_line_char); j ← 0;
      end
    else begin pdf_print(" "); incr(j);
      end;
    incr(i);
  end;
  pdf_buf[pdf_ptr - 1] ← pdf_new_line_char; { no risk of flush, as we are in pdf_os_mode }
  q ← pdf_ptr; pdf_begin_dict(pdf_os_cur_objnum, 0); { switch to PDF stream writing }
  pdf_print_ln("/Type_ObjStm"); pdf_print("/N"); pdf_print_int_ln(pdf_os_objidx + 1);
  pdf_print("/First"); pdf_print_int_ln(q - p); pdf_begin_stream; pdf_room(q - p);
  { should always fit into the PDF output buffer }
  i ← p;
  while i < q do
    begin { write object number and byte offset pairs }
      pdf_quick_out(pdf_os_buf[i]); incr(i);
    end;
  i ← 0;
  while i < p do
    begin q ← i + pdf_buf_size;
    if q > p then q ← p;
    pdf_room(q - i);
    while i < q do
      begin { write the buffered objects }
        pdf_quick_out(pdf_os_buf[i]); incr(i);
      end;
    end;
  pdf_end_stream; pdf_os_cur_objnum ← 0; { to force object stream generation next time }
end;

```

700. 〈Declare procedures that need to be declared forward for pdfTeX 686〉 +≡

```

function append_ptr(p : pointer; i : integer): pointer;
    { appends a pointer with info i to the end of linked list with head p }
    var q: pointer;
    begin append_ptr ← p; fast_get_avail(q); info(q) ← i; link(q) ← null;
    if p = null then
        begin append_ptr ← q; return;
        end;
    while link(p) ≠ null do p ← link(p);
    link(p) ← q;
    end;
function pdf_lookup_list(p : pointer; i : integer): pointer; { looks up for pointer with info i in list p }
    begin pdf_lookup_list ← null;
    while p ≠ null do
        begin if info(p) = i then
            begin pdf_lookup_list ← p; return;
            end;
        p ← link(p);
        end;
    end;

```

701. 〈Global variables 13〉 +≡

```

pdf_image_procset: integer; { collection of image types used in current page/form }
pdf_text_procset: boolean; { mask of used ProcSet's in the current page/form }

```

702. Subroutines to print out various PDF objects:

```

define is_hex_char(#)  $\equiv (((\# \geq \text{'0'}) \wedge (\# \leq \text{'9'})) \vee ((\# \geq \text{'A'}) \wedge (\# \leq \text{'F'})) \vee ((\# \geq \text{'a'}) \wedge (\# \leq \text{'f'})))$ 

procedure pdf_print_fw_int(n : longinteger; w : integer);
    { print out an integer with fixed width; used for outputting cross-reference table }
    var k : integer; { 0 ≤ k ≤ 23 }
    begin k ← 0;
    repeat dig[k] ← n mod 10; n ← n div 10; incr(k);
    until k = w;
    pdf_room(k);
    while k > 0 do
        begin decr(k); pdf_quick_out("0" + dig[k]);
        end;
    end;

procedure pdf_out_bytes(n : longinteger; w : integer);
    { print out an integer as a number of bytes; used for outputting /XRef cross-reference stream }
    var k : integer; byte : array [0 .. 7] of integer; { digits in a number being output }
    begin k ← 0;
    repeat byte[k] ← n mod 256; n ← n div 256; incr(k);
    until k = w;
    pdf_room(k);
    while k > 0 do
        begin decr(k); pdf_quick_out(byte[k]);
        end;
    end;

procedure pdf_int_entry(s : str_number; v : integer);
    { print out an entry in dictionary with integer value to PDF buffer }
    begin pdf_out("/"); pdf_print(s); pdf_out(" "); pdf_print_int(v);
    end;

procedure pdf_int_entry_ln(s : str_number; v : integer);
    begin pdf_int_entry(s, v); pdf_print_nl;
    end;

procedure pdf_indirect(s : str_number; o : integer); { print out an indirect entry in dictionary }
    begin pdf_out("/"); pdf_print(s); pdf_out(" "); pdf_print_int(o); pdf_print("0␣R");
    end;

procedure pdf_indirect_ln(s : str_number; o : integer);
    begin pdf_indirect(s, o); pdf_print_nl;
    end;

procedure pdf_print_str(s : str_number); { print out s as string in PDF output }
    label done;
    var i, j : pool_pointer; is_hex_string : boolean;
    begin i ← str_start[s]; j ← i + length(s) - 1;
    if i > j then
        begin pdf_print("()"); { null string }
        return;
        end;
    if (str_pool[i] = ^(^) ∧ (str_pool[j] = ^)^) then
        begin pdf_print(s); return;
        end;
    is_hex_string ← false;
    if (str_pool[i] ≠ ^<^) ∨ (str_pool[j] ≠ ^>^) ∨ odd(length(s)) then goto done;
    incr(i); decr(j);
    while i < j do

```

```

begin if is_hex_char(str_pool[i])  $\wedge$  is_hex_char(str_pool[i + 1]) then i  $\leftarrow$  i + 2
else goto done;
end;
is_hex_string  $\leftarrow$  true;
done: if is_hex_string then pdf_print(s)
else begin pdf_out("("); pdf_print(s); pdf_out(")");
end;
end;
procedure pdf_print_str_ln(s : str_number); { print out s as string in PDF output }
begin pdf_print_str(s); pdf_print_nl;
end;
procedure pdf_str_entry(s, v : str_number);
    { print out an entry in dictionary with string value to PDF buffer }
begin if v = 0 then return;
pdf_out("/"); pdf_print(s); pdf_out("□"); pdf_print_str(v);
end;
procedure pdf_str_entry_ln(s, v : str_number);
begin if v = 0 then return;
pdf_str_entry(s, v); pdf_print_nl;
end;

```

703. Font processing. As pdfTeX should also act as a back-end driver, it needs to support virtual fonts too. Information about virtual fonts can be found in the source of some DVI-related programs.

Whenever we want to write out a character in a font to PDF output, we should check whether the used font is a new (has not been used yet), virtual or real font. The array *pdf_font_type* holds a flag of each used font. After initialization the flag of each font is set to *new_font_type*. The first time a character of a font is written out, pdfTeX looks for the corresponding virtual font. If the corresponding virtual font exists, then the font type is set to *virtual_font_type*; otherwise it will be set to *real_font_type*. *subst_font_type* indicates fonts that have been substituted during adjusting spacing. Such fonts are linked via the *pdf_font_elink* array.

```

define new_font_type = 0 { new font (has not been used yet) }
define virtual_font_type = 1 { virtual font }
define real_font_type = 2 { real font }
define subst_font_type = 3 { substituted font }

```

⟨ Declare procedures that need to be declared forward for pdfTeX 686 ⟩ +=

```

procedure pdf_check_vf_cur_val; forward;
procedure pdf_init_font_cur_val; forward;
procedure scan_pdf_ext_toks; forward;

```

704. ⟨ Global variables 13 ⟩ +=

```

pdf_font_type: ↑eight_bits; { the type of font }
pdf_font_attr: ↑str_number; { pointer to additional attributes }
pdf_font_nobuiltin_tounicode: ↑boolean; { disable generating ToUnicode for this font? }

```

705. Here come some subroutines to deal with expanded fonts for HZ-algorithm.

```

define set_char_and_font(#) ≡
  if is_char_node(#) then
    begin c ← character(#); f ← font(#);
    end
  else if type(#) = ligature_node then
    begin c ← character(lig_char(#)); f ← font(lig_char(#));
    end
define non_existent_path ≡ "///..."

procedure set_tag_code(f : internal_font_number; c : eight_bits; i : integer);
var fixedi : integer;
begin if is_valid_char(c) then
  begin fixedi ← abs(fix_int(i, -7, 0));
  if fixedi ≥ 4 then
    begin if char_tag(char_info(f)(c)) = ext_tag then
      op_byte(char_info(f)(c)) ← (op_byte(char_info(f)(c))) - ext_tag;
      fixedi ← fixedi - 4;
    end;
    if fixedi ≥ 2 then
      begin if char_tag(char_info(f)(c)) = list_tag then
        op_byte(char_info(f)(c)) ← (op_byte(char_info(f)(c))) - list_tag;
        fixedi ← fixedi - 2;
      end;
      if fixedi ≥ 1 then
        begin if char_tag(char_info(f)(c)) = lig_tag then
          op_byte(char_info(f)(c)) ← (op_byte(char_info(f)(c))) - lig_tag;
        end;
      end;
    end;
  end;
procedure set_no_ligatures(f : internal_font_number);
var c : integer;
begin for c ← font_bc[f] to font_ec[f] do
  if char_exists(orig_char_info(f)(c)) then
    if char_tag(orig_char_info(f)(c)) = lig_tag then
      op_byte(orig_char_info(f)(c)) ← (op_byte(orig_char_info(f)(c))) - lig_tag;
    end;
function init_font_base(v : integer): integer;
var i, j : integer;
begin i ← pdf_get_mem(256);
for j ← 0 to 255 do pdf_mem[i + j] ← v;
init_font_base ← i;
end;
procedure set_lp_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_lp_base[f] = 0 then pdf_font_lp_base[f] ← init_font_base(0);
pdf_mem[pdf_font_lp_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_rp_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_rp_base[f] = 0 then pdf_font_rp_base[f] ← init_font_base(0);
pdf_mem[pdf_font_rp_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_ef_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_ef_base[f] = 0 then pdf_font_ef_base[f] ← init_font_base(1000);

```



```

pdf_mem[pdf_font_ef_base[f] + c] ← fix_int(i, 0, 1000);
end;
procedure set_kn_bs_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_kn_bs_base[f] = 0 then pdf_font_kn_bs_base[f] ← init_font_base(0);
pdf_mem[pdf_font_kn_bs_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_st_bs_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_st_bs_base[f] = 0 then pdf_font_st_bs_base[f] ← init_font_base(0);
pdf_mem[pdf_font_st_bs_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_sh_bs_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_sh_bs_base[f] = 0 then pdf_font_sh_bs_base[f] ← init_font_base(0);
pdf_mem[pdf_font_sh_bs_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_kn_bc_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_kn_bc_base[f] = 0 then pdf_font_kn_bc_base[f] ← init_font_base(0);
pdf_mem[pdf_font_kn_bc_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure set_kn_ac_code(f : internal_font_number; c : eight_bits; i : integer);
begin if pdf_font_kn_ac_base[f] = 0 then pdf_font_kn_ac_base[f] ← init_font_base(0);
pdf_mem[pdf_font_kn_ac_base[f] + c] ← fix_int(i, -1000, 1000);
end;
procedure adjust_interword_glue(p, g : pointer); { adjust the interword glue g after a character p }
var kn, st, sh : scaled; q, r : pointer; c : halfword; f : internal_font_number;
begin if ¬(¬is_char_node(g) ∧ type(g) = glue_node) then
begin pdf_warning("adjust_interword_glue", "glue is not a glue", false, false); return;
end;
c ← non_char; { no char before interword glue yet }
set_char_and_font(p) { set f and c if p is a char or ligature }
else if (type(p) = kern_node) ∧ (subtype(p) = auto_kern) ∧ (save_tail ≠ null) then
begin r ← save_tail;
while (link(r) ≠ null) ∧ (link(r) ≠ p) do r ← link(r);
if (link(r) = p) then set_char_and_font(r); { set f and c if r is a char or ligature }
end;
if (c = non_char) then return;
kn ← get_kn_bs_code(f, c); st ← get_st_bs_code(f, c); sh ← get_sh_bs_code(f, c);
if (kn ≠ 0) ∨ (st ≠ 0) ∨ (sh ≠ 0) then
begin q ← new_spec(glue_ptr(g)); delete_glue_ref(glue_ptr(g));
width(q) ← width(q) + round_xn_over_d(quad(f), kn, 1000);
stretch(q) ← stretch(q) + round_xn_over_d(quad(f), st, 1000);
shrink(q) ← shrink(q) + round_xn_over_d(quad(f), sh, 1000); glue_ptr(g) ← q;
end;
end;
function get_auto_kern(f : internal_font_number; l, r : halfword) : pointer;
{ return a pointer to an auto kern node, or null }
var tmp_w : scaled; k : integer; p : pointer;
begin pdfassert((l ≥ 0) ∧ (r ≥ 0)); get_auto_kern ← null;
if (pdf_append_kern ≤ 0) ∧ (pdf_prepend_kern ≤ 0) then return;
tmp_w ← 0;
if (pdf_append_kern > 0) ∧ (l < non_char) then
begin k ← get_kn_ac_code(f, l);
if k ≠ 0 then tmp_w ← round_xn_over_d(quad(f), k, 1000);

```

```

end;
if (pdf_prepend_kern > 0) ∧ (r < non_char) then
  begin k ← get_kn_bc_code(f, r);
  if k ≠ 0 then tmp_w ← tmp_w + round_xn_over_d(quad(f), k, 1000);
  end;
if tmp_w ≠ 0 then
  begin p ← new_kern(tmp_w); subtype(p) ← auto_kern; get_auto_kern ← p;
  end;
end;
function expand_font_name(f : internal_font_number; e : integer): str_number;
var old_setting: 0 .. max_selector; { holds selector setting }
begin old_setting ← selector; selector ← new_string; print(font_name[f]);
if e > 0 then print("+"); { minus sign will be printed by print_int }
print_int(e); selector ← old_setting; expand_font_name ← make_string;
end;
function auto_expand_font(f : internal_font_number; e : integer): internal_font_number;
{ creates an expanded font from the base font; doesn't load expanded tfm at all }
var k: internal_font_number; nw, nk, ni, i: integer;
begin k ← font_ptr + 1; incr(font_ptr);
if (font_ptr ≥ font_max) then overflow("maximum_internal_font_number(font_max)", font_max);
font_name[k] ← expand_font_name(f, e); font_area[k] ← font_area[f]; font_id_text(k) ← font_id_text(f);
hyphen_char[k] ← hyphen_char[f]; skew_char[k] ← skew_char[f]; font_bchar[k] ← font_bchar[f];
font_false_bchar[k] ← font_false_bchar[f]; font_bc[k] ← font_bc[f]; font_ec[k] ← font_ec[f];
font_size[k] ← font_size[f]; font_dsize[k] ← font_dsize[f]; font_params[k] ← font_params[f];
font_glue[k] ← font_glue[f]; bchar_label[k] ← bchar_label[f]; char_base[k] ← char_base[f];
height_base[k] ← height_base[f]; depth_base[k] ← depth_base[f]; lig_kern_base[k] ← lig_kern_base[f];
exten_base[k] ← exten_base[f]; param_base[k] ← param_base[f]; nw ← height_base[f] - width_base[f];
ni ← lig_kern_base[f] - italic_base[f]; nk ← exten_base[f] - (kern_base[f] + kern_base_offset);
if (fmem_ptr + nw + ni + nk ≥ font_mem_size) then
  overflow("number_of_words_of_font_memory(font_mem_size)", font_mem_size);
width_base[k] ← fmem_ptr; italic_base[k] ← width_base[k] + nw;
kern_base[k] ← italic_base[k] + ni - kern_base_offset; fmem_ptr ← fmem_ptr + nw + ni + nk;
for i ← 0 to nw - 1 do
  font_info[width_base[k] + i].sc ← round_xn_over_d(font_info[width_base[f] + i].sc, 1000 + e, 1000);
for i ← 0 to ni - 1 do
  font_info[italic_base[k] + i].sc ← round_xn_over_d(font_info[italic_base[f] + i].sc, 1000 + e, 1000);
for i ← 0 to nk - 1 do font_info[kern_base[k] + kern_base_offset + i].sc ←
  round_xn_over_d(font_info[kern_base[f] + kern_base_offset + i].sc, 1000 + e, 1000);
auto_expand_font ← k;
end;
procedure copy_expand_params(k, f : internal_font_number; e : integer);
{ set expansion-related parameters for an expanded font k, based on the base font f and the
expansion amount e }
begin if pdf_font_rp_base[f] = 0 then pdf_font_rp_base[f] ← init_font_base(0);
if pdf_font_lp_base[f] = 0 then pdf_font_lp_base[f] ← init_font_base(0);
if pdf_font_ef_base[f] = 0 then pdf_font_ef_base[f] ← init_font_base(1000);
pdf_font_expand_ratio[k] ← e; pdf_font_step[k] ← pdf_font_step[f];
pdf_font_auto_expand[k] ← pdf_font_auto_expand[f]; pdf_font_blink[k] ← f;
pdf_font_lp_base[k] ← pdf_font_lp_base[f]; pdf_font_rp_base[k] ← pdf_font_rp_base[f];
pdf_font_ef_base[k] ← pdf_font_ef_base[f];
if pdf_font_kn_bs_base[f] = 0 then pdf_font_kn_bs_base[f] ← init_font_base(0);
if pdf_font_st_bs_base[f] = 0 then pdf_font_st_bs_base[f] ← init_font_base(0);

```

```

if pdf_font_sh_bs_base[f] = 0 then pdf_font_sh_bs_base[f] ← init_font_base(0);
if pdf_font_kn_bc_base[f] = 0 then pdf_font_kn_bc_base[f] ← init_font_base(0);
if pdf_font_kn_ac_base[f] = 0 then pdf_font_kn_ac_base[f] ← init_font_base(0);
pdf_font_kn_bs_base[k] ← pdf_font_kn_bs_base[f]; pdf_font_st_bs_base[k] ← pdf_font_st_bs_base[f];
pdf_font_sh_bs_base[k] ← pdf_font_sh_bs_base[f]; pdf_font_kn_bc_base[k] ← pdf_font_kn_bc_base[f];
pdf_font_kn_ac_base[k] ← pdf_font_kn_ac_base[f];
end;

function tfm_lookup(s : str_number; fs : scaled): internal_font_number;
    { looks up for a TFM with name s loaded at fs size; if found then flushes s }
var k: internal_font_number;
begin if fs ≠ 0 then
    begin for k ← font_base + 1 to font_ptr do
        if (font_area[k] ≠ non_existent_path) ∧ str_eq_str(font_name[k], s) ∧ (font_size[k] = fs) then
            begin flush_str(s); tfm_lookup ← k; return;
            end;
        end
    else begin for k ← font_base + 1 to font_ptr do
        if (font_area[k] ≠ non_existent_path) ∧ str_eq_str(font_name[k], s) then
            begin flush_str(s); tfm_lookup ← k; return;
            end;
        end;
    end;
    tfm_lookup ← null_font;
end;

function load_expand_font(f : internal_font_number; e : integer): internal_font_number; { loads font f
    expanded by e thousandths into font memory; e is nonzero and is a multiple of pdf_font_step[f] }
label found;
var s: str_number; { font name }
    k: internal_font_number;
begin s ← expand_font_name(f, e); k ← tfm_lookup(s, font_size[f]);
if k = null_font then
    begin if pdf_font_auto_expand[f] then k ← auto_expand_font(f, e)
        else k ← read_font_info(null_cs, s, "", font_size[f]);
        end;
if k ≠ null_font then copy_expand_params(k, f, e);
    load_expand_font ← k;
end;

function fix_expand_value(f : internal_font_number; e : integer): integer;
    { return the multiple of pdf_font_step[f] that is nearest to e }
var step: integer; max_expand: integer; neg: boolean;
begin fix_expand_value ← 0;
if e = 0 then return;
if e < 0 then
    begin e ← -e; neg ← true; max_expand ← -pdf_font_expand_ratio[pdf_font_shrink[f]];
    end
else begin neg ← false; max_expand ← pdf_font_expand_ratio[pdf_font_stretch[f]];
    end;
if e > max_expand then e ← max_expand
else begin step ← pdf_font_step[f];
    if e mod step > 0 then e ← step * round_xn_over_d(e, 1, step);
    end;
if neg then e ← -e;
    fix_expand_value ← e;

```

```

end;
function get_expand_font(f : internal_font_number; e : integer): internal_font_number;
    { look up and create if not found an expanded version of f; f is an expandable font; e is nonzero
      and is a multiple of pdf_font_step[f] }
var k: internal_font_number;
begin k ← pdf_font_elink[f];
while k ≠ null_font do
    begin if pdf_font_expand_ratio[k] = e then
        begin get_expand_font ← k; return;
        end;
    k ← pdf_font_elink[k];
end;
k ← load_expand_font(f, e); pdf_font_elink[k] ← pdf_font_elink[f]; pdf_font_elink[f] ← k;
get_expand_font ← k;
end;
function expand_font(f : internal_font_number; e : integer): internal_font_number;
    { looks up for font f expanded by e thousandths, e is an arbitrary value between max stretch and
      max shrink of f; if not found then creates it }
begin expand_font ← f;
if e = 0 then return;
e ← fix_expand_value(f, e);
if e = 0 then return;
if pdf_font_elink[f] = null_font then pdf_error("font_expansion", "uninitialized_pdf_font_elink");
expand_font ← get_expand_font(f, e);
end;
procedure set_expand_params(f : internal_font_number; auto_expand : boolean;
    stretch_limit, shrink_limit, font_step, expand_ratio : integer);
    { expand a font with given parameters }
begin pdf_font_step[f] ← font_step; pdf_font_auto_expand[f] ← auto_expand;
if stretch_limit > 0 then pdf_font_stretch[f] ← get_expand_font(f, stretch_limit);
if shrink_limit > 0 then pdf_font_shrink[f] ← get_expand_font(f, -shrink_limit);
if expand_ratio ≠ 0 then pdf_font_expand_ratio[f] ← expand_ratio;
end;
procedure vf_expand_local_fonts(f : internal_font_number);
var lf: internal_font_number; k: integer;
begin pdfassert(pdf_font_type[f] = virtual_font_type);
for k ← 0 to vf_local_font_num[f] - 1 do
    begin lf ← vf_i_fnts[vf_default_font[f] + k];
        set_expand_params(lf, pdf_font_auto_expand[f], pdf_font_expand_ratio[pdf_font_stretch[f]],
            -pdf_font_expand_ratio[pdf_font_shrink[f]], pdf_font_step[f], pdf_font_expand_ratio[f]);
        if pdf_font_type[lf] = virtual_font_type then vf_expand_local_fonts(lf);
    end;
end;
procedure read_expand_font; { read font expansion spec and load expanded font }
var shrink_limit, stretch_limit, font_step: integer; f: internal_font_number; auto_expand: boolean;
begin { read font expansion parameters }
scan_font_ident; f ← cur_val;
if f = null_font then pdf_error("font_expansion", "invalid_font_identifier");
if pdf_font_blink[f] ≠ null_font then pdf_error("font_expansion",
    "\pdffontexpand_cannot_be_used_this_way(the_base_font_has_been_expanded)");
scan_optional_equals; scan_int; stretch_limit ← fix_int(cur_val, 0, 1000); scan_int;
shrink_limit ← fix_int(cur_val, 0, 500); scan_int; font_step ← fix_int(cur_val, 0, 100);

```

```

if font_step = 0 then pdf_error("font_expansion","invalid_step");
stretch_limit ← stretch_limit − stretch_limit mod font_step;
if stretch_limit < 0 then stretch_limit ← 0;
shrink_limit ← shrink_limit − shrink_limit mod font_step;
if shrink_limit < 0 then shrink_limit ← 0;
if (stretch_limit = 0) ∧ (shrink_limit = 0) then pdf_error("font_expansion","invalid_limit(s)");
auto_expand ← false;
if scan_keyword("autoexpand") then
  begin auto_expand ← true; { Scan an optional space 469 };
  end; { check if the font can be expanded }
if (pdf_font_expand_ratio[f] ≠ 0) then pdf_error("font_expansion",
  "this_font_has_been_expanded_by_another_font_so_it_cannot_be_used_now");
if (pdf_font_step[f] ≠ 0) then
  { this font has been expanded, ensure the expansion parameters are identical }
  begin if pdf_font_step[f] ≠ font_step then
    pdf_error("font_expansion","font_has_been_expanded_with_different_expansion_step");
  if ((pdf_font_stretch[f] = null_font) ∧ (stretch_limit ≠ 0)) ∨ ((pdf_font_stretch[f] ≠
    null_font) ∧ (pdf_font_expand_ratio[pdf_font_stretch[f]] ≠ stretch_limit)) then
    pdf_error("font_expansion","font_has_been_expanded_with_different_stretch_limit");
  if ((pdf_font_shrink[f] = null_font) ∧ (shrink_limit ≠ 0)) ∨ ((pdf_font_shrink[f] ≠
    null_font) ∧ (−pdf_font_expand_ratio[pdf_font_shrink[f]] ≠ shrink_limit)) then
    pdf_error("font_expansion","font_has_been_expanded_with_different_shrink_limit");
  if pdf_font_auto_expand[f] ≠ auto_expand then pdf_error("font_expansion",
    "font_has_been_expanded_with_different_auto_expansion_value");
  end
else begin if (pdf_font_type[f] ≠ new_font_type) ∧ (pdf_font_type[f] ≠ virtual_font_type) then
  pdf_warning("font_expansion","font_should_be_expanded_before_its_first_use", true, true);
  set_expand_params(f, auto_expand, stretch_limit, shrink_limit, font_step, 0);
  if pdf_font_type[f] = virtual_font_type then vf_expand_local_fonts(f);
  end;
end;

```

706. We implement robust letter spacing using virtual font.

```

define vf_replace_z  $\equiv$ 
  begin vf_alpha  $\leftarrow$  16;
  while vf_z  $\geq$  '40000000' do
    begin vf_z  $\leftarrow$  vf_z div 2; vf_alpha  $\leftarrow$  vf_alpha + vf_alpha;
    end;
  vf_beta  $\leftarrow$  256 div vf_alpha; vf_alpha  $\leftarrow$  vf_alpha * vf_z;
  end

function letter_space_font(u : pointer; f : internal_font_number; e : integer): internal_font_number;
  var k: internal_font_number; w, r: scaled; s: str_number; i, nw: integer; old_setting: 0 .. max_selector;
  vf_z: integer; vf_alpha: integer; vf_beta: 1 .. 16;
  begin { read a new font and expand the character widths }
  k  $\leftarrow$  read_font_info(u, font_name[f], "", font_size[f]);
  if scan_keyword("nolig") then set_no_ligatures(k); { disable ligatures for letter-spaced fonts }
  nw  $\leftarrow$  height_base[k] - width_base[k];
  for i  $\leftarrow$  0 to nw - 1 do
    font_info[width_base[k] + i].sc  $\leftarrow$  font_info[width_base[k] + i].sc + round_xn_over_d(quad(k), e, 1000);
    { append, e.g., '+100ls' to font name }
  flush_str(font_name[k]); str_room(length(font_name[k] + 7); { abs(e)  $\leq$  1000 }
  old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string; print(font_name[k]);
  if e > 0 then print("+"); { minus sign will be printed by print_int }
  print_int(e); print("ls"); selector  $\leftarrow$  old_setting; font_name[k]  $\leftarrow$  make_string;
  { create the corresponding virtual font }
  allocvffnts; vf_e_fnts[vf_nf]  $\leftarrow$  0; vf_i_fnts[vf_nf]  $\leftarrow$  f; incr(vf_nf); vf_local_font_num[k]  $\leftarrow$  1;
  vf_default_font[k]  $\leftarrow$  vf_nf - 1; pdf_font_type[k]  $\leftarrow$  virtual_font_type; vf_z  $\leftarrow$  font_size[f]; vf_replace_z;
  w  $\leftarrow$  round_xn_over_d(quad(f), e, 2000);
  if w  $\geq$  0 then tmp_b0  $\leftarrow$  0
  else begin tmp_b0  $\leftarrow$  255; w  $\leftarrow$  vf_alpha + w;
    end;
  r  $\leftarrow$  w * vf_beta; tmp_b1  $\leftarrow$  r div vf_z; r  $\leftarrow$  r mod vf_z;
  if r = 0 then tmp_b2  $\leftarrow$  0
  else begin r  $\leftarrow$  r * 256; tmp_b2  $\leftarrow$  r div vf_z; r  $\leftarrow$  r mod vf_z;
    end;
  if r = 0 then tmp_b3  $\leftarrow$  0
  else begin r  $\leftarrow$  r * 256; tmp_b3  $\leftarrow$  r div vf_z;
    end;
  vf_packet_base[k]  $\leftarrow$  new_vf_packet(k);
  for c  $\leftarrow$  font_bc[k] to font_ec[k] do
    begin str_room(12); append_char(right1 + 3); append_char(tmp_b0); append_char(tmp_b1);
    append_char(tmp_b2); append_char(tmp_b3);
    if c < set1 then append_char(c)
    else begin append_char(set1); append_char(c);
      end;
    append_char(right1 + 3); append_char(tmp_b0); append_char(tmp_b1); append_char(tmp_b2);
    append_char(tmp_b3); s  $\leftarrow$  make_string; storepacket(k, c, s); flush_str(s);
    end;
  letter_space_font  $\leftarrow$  k;
  end;

procedure new_letterspaced_font(a : small_number); { letter-space a font by creating a virtual font }
  var u: pointer; { user's font identifier }
  t: str_number; { name for the frozen font identifier }
  old_setting: 0 .. max_selector; { holds selector setting }

```

```

    f, k: internal_font_number;
begin get_r_token; u ← cur_cs;
if u ≥ hash_base then t ← text(u)
else if u ≥ single_base then
    if u = null_cs then t ← "FONT" else t ← u − single_base
    else begin old_setting ← selector; selector ← new_string; print("FONT"); print(u − active_base);
        selector ← old_setting; str_room(1); t ← make_string;
    end;
    define(u, set_font, null_font); scan_optional_equals; scan_font_ident; k ← cur_val; scan_int;
    f ← letter_space_font(u, k, fix_int(cur_val, −1000, 1000)); equiv(u) ← f; eqtb[font_id_base + f] ← eqtb[u];
    font_id_text(f) ← t;
end;
function is_letterspaced_font(f : internal_font_number): boolean;
    label done;
    var i, j: pool_pointer;
    begin is_letterspaced_font ← false;
    if pdf_font_type[f] ≠ virtual_font_type then return;
    i ← str_start[font_name[f] + 1] − 1; j ← str_start[font_name[f]];
    if (str_pool[i − 1] ≠ '1') ∨ (str_pool[i] ≠ 's') then return;
    i ← i − 2;
    while i ≥ j do
        begin if (str_pool[i] < '0') ∨ (str_pool[i] > '9') then goto done;
        i ← i − 1;
    end;
done: if i < j then return;
    if (str_pool[i] ≠ '+' ) ∧ (str_pool[i] ≠ '-' ) then return;
    is_letterspaced_font ← true;
end;
function copy_font_info(f : internal_font_number): internal_font_number;
    { create a copy of f in the font mem }
    var lf, bc, ec, i: halfword; k: internal_font_number;
    begin if (pdf_font_expand_ratio[f] ≠ 0) ∨ (pdf_font_step[f] ≠ 0) then
        pdf_error("pdfcopyfont", "cannot copy an expanded font");
    if is_letterspaced_font(f) then pdf_error("pdfcopyfont", "cannot copy a letterspaced font");
    k ← font_ptr + 1; incr(font_ptr);
    if (font_ptr ≥ font_max) then overflow("maximum internal font number", font_max);
    font_name[k] ← font_name[f]; font_area[k] ← non_existent_path;
    { to avoid interferences with new_font() and tfm_lookup() }
    hyphen_char[k] ← hyphen_char[f]; skew_char[k] ← skew_char[f]; font_bchar[k] ← font_bchar[f];
    font_false_bchar[k] ← font_false_bchar[f]; font_bc[k] ← font_bc[f]; font_ec[k] ← font_ec[f];
    font_size[k] ← font_size[f]; font_dsize[k] ← font_dsize[f]; font_params[k] ← font_params[f];
    font_glue[k] ← font_glue[f]; bchar_label[k] ← bchar_label[f]; { set base addresses }
    bc ← font_bc[f]; ec ← font_ec[f]; char_base[k] ← fmem_ptr − bc; width_base[k] ← char_base[k] + ec + 1;
    height_base[k] ← width_base[k] + (height_base[f] − width_base[f]);
    depth_base[k] ← height_base[k] + (depth_base[f] − height_base[f]);
    italic_base[k] ← depth_base[k] + (italic_base[f] − depth_base[f]);
    lig_kern_base[k] ← italic_base[k] + (lig_kern_base[f] − italic_base[f]);
    kern_base[k] ← lig_kern_base[k] + (kern_base[f] − lig_kern_base[f]);
    exten_base[k] ← kern_base[k] + (exten_base[f] − kern_base[f]);
    param_base[k] ← exten_base[k] + (param_base[f] − exten_base[f]);
    { allocate memory for the new font k and copy data from f }
    lf ← (param_base[f] − char_base[f]) + font_params[f] + 1;

```

```

if (fmem_ptr + lf ≥ font_mem_size) then
  overflow("number_of_words_of_font_memory(",font_mem_size);
for i ← 0 to lf − 1 do font_info[char_base[k] + bc + i] ← font_info[char_base[f] + bc + i];
fmem_ptr ← fmem_ptr + lf; copy_font_info ← k;
end;

procedure make_font_copy(a : small_number); { make a font copy for further use with font expansion }
var u: pointer; { user's font identifier }
    t: str_number; { name for the frozen font identifier }
    old_setting: 0 .. max_selector; { holds selector setting }
    f, k: internal_font_number;
begin get_r_token; u ← cur_cs;
if u ≥ hash_base then t ← text(u)
else if u ≥ single_base then
  if u = null_cs then t ← "FONT" else t ← u − single_base
else begin old_setting ← selector; selector ← new_string; print("FONT"); print(u − active_base);
  selector ← old_setting; str_room(1); t ← make_string;
end;
define(u, set_font, null_font); scan_optional_equals; scan_font_ident; k ← cur_val; f ← copy_font_info(k);
equiv(u) ← f; eqtb[font_id_base + f] ← eqtb[u]; font_id_text(f) ← t;
end;

```

707. We need to hold information about used characters in each font for partial downloading.

```

⟨Types in the outer block 18⟩ +≡
  char_used_array = array [0 .. 31] of eight_bits;
  char_map_array = array [0 .. 32] of eight_bits; { move chars in range 0..32 }
  fm_entry_ptr = ↑integer;

```

708. ⟨Global variables 13⟩ +≡

```

pdf_char_used: ↑char_used_array; { to mark used chars }
pdf_font_size: ↑scaled; { used size of font in PDF file }
pdf_font_num: ↑integer;
  { mapping between internal font number in TEX and font name defined in resources in PDF file }
pdf_font_map: ↑fm_entry_ptr; { pointer into AVL tree of font mappings }
pdf_font_list: pointer; { list of used fonts in current page }
pdf_resname_prefix: str_number; { global prefix of resources name }
last_tokens_string: str_number; { the number of the most recently string created by tokens_to_string }

```

709. ⟨Set initial values of key variables 21⟩ +≡

```

pdf_resname_prefix ← 0; last_tokens_string ← 0;

```


710. Here we implement reading information from VF file.

```

define vf_max_packet_length = 10000 { max length of character packet in VF file }
define do_char = 70 { label to go to typesetting a character of virtual font }
define long_char = 242 { VF command for general character packet }
define vf_id = 202 { identifies VF files }
define put1 = 133 { typeset a character }
define four_cases(#)  $\equiv$  #, # + 1, # + 2, # + 3
define tmp_b0  $\equiv$  tmp_w.qqqq.b0
define tmp_b1  $\equiv$  tmp_w.qqqq.b1
define tmp_b2  $\equiv$  tmp_w.qqqq.b2
define tmp_b3  $\equiv$  tmp_w.qqqq.b3
define tmp_int  $\equiv$  tmp_w.int
define bad_vf(#)  $\equiv$  vf_error(font_name[f], #) { quit with an error message telling the vf filename }

```

⟨Global variables 13⟩ +=

```

vf_packet_base: ↑integer; { base addresses of character packets from virtual fonts }
vf_default_font: ↑internal_font_number; { default font in a VF file }
vf_local_font_num: ↑internal_font_number; { number of local fonts in a VF file }
vf_packet_length: integer; { length of the current packet }
vf_file: byte_file;
vf_nf: internal_font_number; { the local fonts counter }
vf_e_fnts: ↑integer; { external font numbers }
vf_i_fnts: ↑internal_font_number; { corresponding internal font numbers }
tmp_w: memory_word; { accumulator }

```

711. ⟨Set initial values of key variables 21⟩ +=

```

vf_nf  $\leftarrow$  0;

```

712. The *do_vf* procedure attempts to read the VF file for a font, and sets *pdf_font_type* to *real_font_type* if the VF file could not be found or loaded, otherwise sets *pdf_font_type* to *virtual_font_type*. To process font definitions in virtual font we call *vf_def_font*.

```

procedure vf_error(filename, msg : str_number);
  var old_setting: 0 .. max_selector; { holds print selector }
  s: str_number;
  begin str_room(length(filename) + 3); old_setting ← selector; selector ← new_string; print(filename);
  print(".vf"); s ← make_string; selector ← old_setting; pdf_error(s, msg);
  end;

function vf_byte: eight_bits; { read a byte from vf_file }
  var i: integer;
  begin i ← getc(vf_file);
  if i < 0 then pdf_error("vf", "unexpected_EOF_or_error");
  vf_byte ← i;
  end;

function vf_read_signed(k : integer): integer; { read k bytes as an signed integer from VF file }
  var i: integer;
  begin pdfassert((k > 0) ∧ (k ≤ 4)); i ← vf_byte;
  if i ≥ 128 then i ← i − 256;
  decr(k);
  while k > 0 do
    begin i ← i * 256 + vf_byte; decr(k);
    end;
  vf_read_signed ← i;
  end;

function vf_read_unsigned(k : integer): integer; { read k bytes as an unsigned integer from VF file }
  var i: integer;
  begin pdfassert((k > 0) ∧ (k ≤ 4)); i ← vf_byte;
  if (k = 4) ∧ (i ≥ 128) then bad_vf("number_too_big");
  decr(k);
  while k > 0 do
    begin i ← i * 256 + vf_byte; decr(k);
    end;
  vf_read_unsigned ← i;
  end;

procedure vf_local_font_warning(f, k : internal_font_number; s : str_number);
  { print a warning message if an error occurs during processing local fonts in VF file }
  begin print_nl(s); print("_in_local_font_"); print(font_name[k]); print("_in_virtual_font_");
  print(font_name[f]); print(".vf_ignored.");
  end;

function vf_def_font(f : internal_font_number): internal_font_number; { process a local font in VF file }
  var k: internal_font_number; s: str_number; ds, fs: scaled; cs: four_quarters;
  begin cs.b0 ← vf_byte; cs.b1 ← vf_byte; cs.b2 ← vf_byte; cs.b3 ← vf_byte;
  fs ← store_scaled_f(vf_read_signed(4), font_size[f]); ds ← vf_read_signed(4) div '20; tmp_b0 ← vf_byte;
  tmp_b1 ← vf_byte;
  while tmp_b0 > 0 do
    begin decr(tmp_b0); call_func(vf_byte); { skip the font path }
    end;
  str_room(tmp_b1);
  while tmp_b1 > 0 do
    begin decr(tmp_b1); append_char(vf_byte);
    end;

```

```

s ← make_string; k ← tfm_lookup(s, fs);
if k = null_font then k ← read_font_info(null_cs, s, "", fs);
if k ≠ null_font then
  begin if ((cs.b0 ≠ 0) ∨ (cs.b1 ≠ 0) ∨ (cs.b2 ≠ 0) ∨ (cs.b3 ≠ 0)) ∧ ((font_check[k].b0 ≠
    0) ∨ (font_check[k].b1 ≠ 0) ∨ (font_check[k].b2 ≠ 0) ∨ (font_check[k].b3 ≠ 0)) ∧ ((cs.b0 ≠
    font_check[k].b0) ∨ (cs.b1 ≠ font_check[k].b1) ∨ (cs.b2 ≠ font_check[k].b2) ∨ (cs.b3 ≠
    font_check[k].b3)) then vf_local_font_warning(f, k, "checksum_mismatch");
  if ds ≠ font_dsize[k] then vf_local_font_warning(f, k, "design_size_mismatch");
  if (pdf_font_step[f] ≠ 0) then
    set_expand_params(k, pdf_font_auto_expand[f], pdf_font_expand_ratio[pdf_font_stretch[f]],
      −pdf_font_expand_ratio[pdf_font_shrink[f]], pdf_font_step[f], pdf_font_expand_ratio[f]);
  end;
  vf_def_font ← k;
end;
procedure do_vf(f : internal_font_number); { process VF file with font internal number f }
  var cmd, k, n: integer; cc, cmd_length, packet_length: integer; tfm_width: scaled; s: str_number;
  stack_level: vf_stack_index; save_vf_nf: internal_font_number;
  begin pdf_font_type[f] ← real_font_type;
  if auto_expand_vf(f) then return; { auto-expanded virtual font }
  stack_level ← 0; ⟨ Open vf_file, return if not found 713 ⟩;
  ⟨ Process the preamble 714 ⟩;
  ⟨ Process the font definitions 715 ⟩;
  ⟨ Allocate memory for the new virtual font 716 ⟩;
  while cmd ≤ long_char do
    begin ⟨ Build a character packet 717 ⟩;
    end;
  if cmd ≠ post then bad_vf("POST_command_expected");
  b_close(vf_file); pdf_font_type[f] ← virtual_font_type;
end;

```

713. ⟨ Open vf_file, return if not found 713 ⟩ ≡
 pack_file_name(font_name[f], "", ".vf");
if ¬vf_b_open_in(vf_file) **then return**

This code is used in section 712.

714. ⟨ Process the preamble 714 ⟩ ≡
if vf_byte ≠ pre **then** bad_vf("PRE_command_expected");
if vf_byte ≠ vf_id **then** bad_vf("wrong_id_byte");
 cmd_length ← vf_byte;
for k ← 1 **to** cmd_length **do** call_func(vf_byte); { skip the comment }
 tmp_b0 ← vf_byte; tmp_b1 ← vf_byte; tmp_b2 ← vf_byte; tmp_b3 ← vf_byte;
if ((tmp_b0 ≠ 0) ∨ (tmp_b1 ≠ 0) ∨ (tmp_b2 ≠ 0) ∨ (tmp_b3 ≠ 0)) ∧ ((font_check[f].b0 ≠
 0) ∨ (font_check[f].b1 ≠ 0) ∨ (font_check[f].b2 ≠ 0) ∨ (font_check[f].b3 ≠ 0)) ∧ ((tmp_b0 ≠
 font_check[f].b0) ∨ (tmp_b1 ≠ font_check[f].b1) ∨ (tmp_b2 ≠ font_check[f].b2) ∨ (tmp_b3 ≠
 font_check[f].b3)) **then**
begin print_nl("checksum_mismatch_in_font"); print(font_name[f]); print(".vf_ignored");
end;
if vf_read_signed(4) div '20 ≠ font_dsize[f] **then**
begin print_nl("design_size_mismatch_in_font"); print(font_name[f]); print(".vf_ignored");
end;
 update_terminal

This code is used in section 712.

715. \langle Process the font definitions 715 $\rangle \equiv$

```
cmd ← vf_byte; save_vf_nf ← vf_nf;
while (cmd ≥ fnt_def1) ∧ (cmd ≤ fnt_def1 + 3) do
  begin allocvffnts; vf_e_fnts[vf_nf] ← vf_read_unsigned(cmd - fnt_def1 + 1);
  vf_i_fnts[vf_nf] ← vf_def_font(f); incr(vf_nf); cmd ← vf_byte;
  end;
vf_default_font[f] ← save_vf_nf; vf_local_font_num[f] ← vf_nf - save_vf_nf;
```

This code is used in section 712.

716. \langle Allocate memory for the new virtual font 716 $\rangle \equiv$

```
vf_packet_base[f] ← new_vf_packet(f)
```

This code is used in section 712.

717. \langle Build a character packet 717 $\rangle \equiv$

```
if cmd = long_char then
  begin packet_length ← vf_read_unsigned(4); cc ← vf_read_unsigned(4);
  if ¬is_valid_char(cc) then bad_vf("invalid_character_code");
  tfm_width ← store_scaled_f(vf_read_signed(4), font_size[f]);
  end
else begin packet_length ← cmd; cc ← vf_byte;
  if ¬is_valid_char(cc) then bad_vf("invalid_character_code");
  tfm_width ← store_scaled_f(vf_read_unsigned(3), font_size[f]);
  end;
if packet_length < 0 then bad_vf("negative_packet_length");
if packet_length > vf_max_packet_length then bad_vf("packet_length_too_long");
if tfm_width ≠ char_width(f)(char_info(f)(cc)) then
  begin print_nl("character_width_mismatch_in_font"); print(font_name[f]);
  print(".vf_ignored");
  end;
str_room(packet_length);
while packet_length > 0 do
  begin cmd ← vf_byte; decr(packet_length);
   $\langle$  Cases of DVI commands that can appear in character packet 719  $\rangle$ ;
  if cmd ≠ nop then append_char(cmd);
  packet_length ← packet_length - cmd_length;
  while cmd_length > 0 do
    begin decr(cmd_length); append_char(vf_byte);
    end;
  end;
if stack_level ≠ 0 then bad_vf("more_PUSHs_than_POPs_in_character_packet");
if packet_length ≠ 0 then bad_vf("invalid_packet_length_or_DVI_command_in_packet");
 $\langle$  Store the packet being built 718  $\rangle$ ;
cmd ← vf_byte
```

This code is used in section 712.

718. \langle Store the packet being built 718 $\rangle \equiv$

```
s ← make_string; storepacket(f, cc, s); flush_str(s)
```

This code is used in section 717.

```

719.  ⟨ Cases of DVI commands that can appear in character packet 719 ⟩ ≡
if (cmd ≥ set_char_0) ∧ (cmd ≤ set_char_0 + 127) then cmd_length ← 0
else if ((fnt_num_0 ≤ cmd) ∧ (cmd ≤ fnt_num_0 + 63)) ∨ ((fnt1 ≤ cmd) ∧ (cmd ≤ fnt1 + 3)) then
  begin if cmd ≥ fnt1 then
    begin k ← vf_read_unsigned(cmd − fnt1 + 1); packet_length ← packet_length − (cmd − fnt1 + 1);
    end
  else k ← cmd − fnt_num_0;
  if k ≥ 256 then bad_vf("too_many_local_fonts");
  n ← 0;
  while (n < vf_local_font_num[f]) ∧ (vf_e_fnts[vf_default_font[f] + n] ≠ k) do incr(n);
  if n = vf_local_font_num[f] then bad_vf("undefined_local_font");
  if k ≤ 63 then append_char(fnt_num_0 + k);
  else begin append_char(fnt1); append_char(k);
  end;
  cmd_length ← 0; cmd ← nop;
end
else case cmd of
  set_rule, put_rule: cmd_length ← 8;
  four_cases(set1): cmd_length ← cmd − set1 + 1;
  four_cases(put1): cmd_length ← cmd − put1 + 1;
  four_cases(right1): cmd_length ← cmd − right1 + 1;
  four_cases(w1): cmd_length ← cmd − w1 + 1;
  four_cases(x1): cmd_length ← cmd − x1 + 1;
  four_cases(down1): cmd_length ← cmd − down1 + 1;
  four_cases(y1): cmd_length ← cmd − y1 + 1;
  four_cases(z1): cmd_length ← cmd − z1 + 1;
  four_cases(xxx1): begin cmd_length ← vf_read_unsigned(cmd − xxx1 + 1);
    packet_length ← packet_length − (cmd − xxx1 + 1);
    if cmd_length > vf_max_packet_length then bad_vf("packet_length_too_long");
    if cmd_length < 0 then bad_vf("string_of_negative_length");
    append_char(xxx1); append_char(cmd_length); cmd ← nop;
    { cmd has been already stored above as xxx1 }
  end;
  w0, x0, y0, z0, nop: cmd_length ← 0;
  push, pop: begin cmd_length ← 0;
    if cmd = push then
      if stack_level = vf_stack_size then overflow("virtual_font_stack_size", vf_stack_size)
      else incr(stack_level)
    else if stack_level = 0 then bad_vf("more_POPs_than_PUSHs_in_character")
    else decr(stack_level);
    end;
  othercases bad_vf("improper_DVI_command");
endcases

```

This code is used in section 717.

720.
procedure *pdf_check_vf_cur_val*;
 var *f*: *internal_font_number*;
 begin *f* \leftarrow *cur_val*; *do_vf*(*f*);
 if *pdf_font_type*[*f*] = *virtual_font_type* **then**
 pdf_error("font", "command cannot be used with virtual font");
 end;
function *auto_expand_vf*(*f*: *internal_font_number*): *boolean*; { check for a virtual auto-expanded font }
 var *bf*, *lf*: *internal_font_number*; *e*, *k*: *integer*;
 begin *auto_expand_vf* \leftarrow *false*;
 if (\neg *pdf_font_auto_expand*[*f*]) \vee (*pdf_font_blink*[*f*] = *null_font*) **then return**;
 { not an auto-expanded font }
 bf \leftarrow *pdf_font_blink*[*f*];
 if *pdf_font_type*[*bf*] = *new_font_type* **then** { we must process the base font first }
 do_vf(*bf*);
 if *pdf_font_type*[*bf*] \neq *virtual_font_type* **then return**; { not a virtual font }
 e \leftarrow *pdf_font_expand_ratio*[*f*];
 for *k* \leftarrow 0 **to** *vf_local_font_num*[*bf*] - 1 **do**
 begin *lf* \leftarrow *vf_default_font*[*bf*] + *k*; *allocvffnts*; { copy vf local font numbers: }
 vf_e_fnts[*vf_nf*] \leftarrow *vf_e_fnts*[*lf*]; { definition of local vf fonts are expanded from base fonts: }
 vf_i_fnts[*vf_nf*] \leftarrow *auto_expand_font*(*vf_i_fnts*[*lf*], *e*);
 copy_expand_params(*vf_i_fnts*[*vf_nf*], *vf_i_fnts*[*lf*], *e*); *incr*(*vf_nf*);
 end;
 vf_packet_base[*f*] \leftarrow *vf_packet_base*[*bf*]; *vf_local_font_num*[*f*] \leftarrow *vf_local_font_num*[*bf*];
 vf_default_font[*f*] \leftarrow *vf_nf* - *vf_local_font_num*[*f*]; *pdf_font_type*[*f*] \leftarrow *virtual_font_type*;
 auto_expand_vf \leftarrow *true*;
end;

721. The *do_vf_packet* procedure is called in order to interpret the character packet for a virtual character. Such a packet may contain the instruction to typeset a character from the same or an other virtual font; in such cases *do_vf_packet* calls itself recursively. The recursion level, i.e., the number of times this has happened, is kept in the global variable *vf_cur_s* and should not exceed *vf_max_recursion*.

< Constants in the outer block 11 > +=

vf_max_recursion = 10; { VF files shouldn't recurse beyond this level }
vf_stack_size = 100; { DVI files shouldn't push beyond this depth }

722. < Types in the outer block 18 > +=

vf_stack_index = 0 .. *vf_stack_size*; { an index into the stack }
vf_stack_record = **record** *stack_h*, *stack_v*, *stack_w*, *stack_x*, *stack_y*, *stack_z*: *scaled*;
end;

723. < Global variables 13 > +=

vf_cur_s: 0 .. *vf_max_recursion*; { current recursion level }
vf_stack: **array** [*vf_stack_index*] **of** *vf_stack_record*;
vf_stack_ptr: *vf_stack_index*; { pointer into *vf_stack* }

724. < Set initial values of key variables 21 > +=

vf_cur_s \leftarrow 0; *vf_stack_ptr* \leftarrow 0;

725. Some functions for processing character packets.

```

function packet_read_signed(k : integer): integer;
    { read k bytes as a signed integer from character packet }
    var i: integer;
    begin pdfassert((k > 0) ∧ (k ≤ 4)); i ← packet_byte;
    if i ≥ 128 then i ← i − 256;
    decr(k);
    while k > 0 do
        begin i ← i * 256 + packet_byte; decr(k);
        end;
    packet_read_signed ← i;
    end;

function packet_read_unsigned(k : integer): integer;
    { read k bytes as an unsigned integer from character packet }
    var i: integer;
    begin pdfassert((k > 0) ∧ (k ≤ 4)); i ← packet_byte;
    if (k = 4) ∧ (i ≥ 128) then bad_vf("number_too_big");
    decr(k);
    while k > 0 do
        begin i ← i * 256 + packet_byte; decr(k);
        end;
    packet_read_unsigned ← i;
    end;

function packet_scaled(k : integer; fs : scaled): scaled; { get k bytes from packet as scaled }
    begin packet_scaled ← store_scaled_f(packet_read_signed(k), fs);
    end;

procedure do_vf_packet(vf_f : internal_font_number; c : eight_bits);
    { typeset the DVI commands in the character packet for character c in current font f }
    label do_char, continue;
    var f, k, n: internal_font_number; save_cur_h, save_cur_v: scaled; cmd: integer; char_move: boolean;
    w, x, y, z: scaled; s: str_number;
    begin incr(vf_cur_s);
    if vf_cur_s > vf_max_recursion then
        overflow("max_level_recursion_of_virtual_fonts", vf_max_recursion);
    save_cur_v ← cur_v; save_cur_h ← cur_h; push_packet_state;
        { save pointer and length of the current packet }
    start_packet(vf_f, c); { set pointer and length of the new packet }
    f ← vf_i_fnts[vf_default_font[vf_f]]; w ← 0; x ← 0; y ← 0; z ← 0;
    while vf_packet_length > 0 do
        begin cmd ← packet_byte; ⟨ Do typesetting the DVI commands in virtual character packet 726 ⟩;
        continue: end;
    pop_packet_state; { restore pointer and length of the previous packet }
    cur_v ← save_cur_v; cur_h ← save_cur_h; decr(vf_cur_s);
    end;

```

726. The following code typesets a character to PDF output.

```

define output_one_char(#)  $\equiv$ 
  begin if pdf_font_type[f] = new_font_type then do_vf(f);
  if pdf_font_type[f] = virtual_font_type then do_vf_packet(f, #)
  else begin pdf_begin_string(f); pdf_print_char(f, #); adv_char_width(f, #);
    end;
  end

(Do typesetting the DVI commands in virtual character packet 726)  $\equiv$ 
if (cmd  $\geq$  set_char_0)  $\wedge$  (cmd  $\leq$  set_char_0 + 127) then
  begin if  $\neg$ is_valid_char(cmd) then
    begin char_warning(f, cmd); goto continue;
    end;
  c  $\leftarrow$  cmd; char_move  $\leftarrow$  true; goto do_char;
  end
else if ((fnt_num_0  $\leq$  cmd)  $\wedge$  (cmd  $\leq$  fnt_num_0 + 63))  $\vee$  (cmd = fnt1) then
  begin if cmd = fnt1 then k  $\leftarrow$  packet_byte
  else k  $\leftarrow$  cmd - fnt_num_0;
  n  $\leftarrow$  0;
  while (n < vf_local_font_num[vf_f])  $\wedge$  (vf_e_fnts[vf_default_font[vf_f] + n]  $\neq$  k) do incr(n);
  if (n = vf_local_font_num[vf_f]) then pdf_error("vf", "local_font_not_found")
  else f  $\leftarrow$  vf_i_fnts[vf_default_font[vf_f] + n];
  end
else case cmd of
  push: begin vf_stack[vf_stack_ptr].stack_h  $\leftarrow$  cur_h; vf_stack[vf_stack_ptr].stack_v  $\leftarrow$  cur_v;
    vf_stack[vf_stack_ptr].stack_w  $\leftarrow$  w; vf_stack[vf_stack_ptr].stack_x  $\leftarrow$  x;
    vf_stack[vf_stack_ptr].stack_y  $\leftarrow$  y; vf_stack[vf_stack_ptr].stack_z  $\leftarrow$  z; incr(vf_stack_ptr);
    end;
  pop: begin decr(vf_stack_ptr); cur_h  $\leftarrow$  vf_stack[vf_stack_ptr].stack_h;
    cur_v  $\leftarrow$  vf_stack[vf_stack_ptr].stack_v; w  $\leftarrow$  vf_stack[vf_stack_ptr].stack_w;
    x  $\leftarrow$  vf_stack[vf_stack_ptr].stack_x; y  $\leftarrow$  vf_stack[vf_stack_ptr].stack_y;
    z  $\leftarrow$  vf_stack[vf_stack_ptr].stack_z;
    end;
  four_cases(set1), four_cases(put1): begin if (set1  $\leq$  cmd)  $\wedge$  (cmd  $\leq$  set1 + 3) then
    begin tmp_int  $\leftarrow$  packet_read_unsigned(cmd - set1 + 1); char_move  $\leftarrow$  true;
    end
  else begin tmp_int  $\leftarrow$  packet_read_unsigned(cmd - put1 + 1); char_move  $\leftarrow$  false;
    end;
  if  $\neg$ is_valid_char(tmp_int) then
    begin char_warning(f, tmp_int); goto continue;
    end;
  c  $\leftarrow$  tmp_int; goto do_char;
  end;
  set_rule, put_rule: begin rule_ht  $\leftarrow$  packet_scaled(4, font_size[vf_f]);
    rule_wd  $\leftarrow$  packet_scaled(4, font_size[vf_f]);
    if (rule_wd > 0)  $\wedge$  (rule_ht > 0) then
      begin pdf_set_rule(cur_h, cur_v, rule_wd, rule_ht);
      if cmd = set_rule then cur_h  $\leftarrow$  cur_h + rule_wd;
      end;
    end;
  four_cases(right1): cur_h  $\leftarrow$  cur_h + packet_scaled(cmd - right1 + 1, font_size[vf_f]);
  w0, four_cases(w1): begin if cmd > w0 then w  $\leftarrow$  packet_scaled(cmd - w0, font_size[vf_f]);
    cur_h  $\leftarrow$  cur_h + w;

```



```

    end;
    x0, four_cases(x1): begin if cmd > x0 then x ← packet_scaled(cmd - x0, font_size[vf-f]);
    cur_h ← cur_h + x;
    end;
    four_cases(down1): cur_v ← cur_v + packet_scaled(cmd - down1 + 1, font_size[vf-f]);
    y0, four_cases(y1): begin if cmd > y0 then y ← packet_scaled(cmd - y0, font_size[vf-f]);
    cur_v ← cur_v + y;
    end;
    z0, four_cases(z1): begin if cmd > z0 then z ← packet_scaled(cmd - z0, font_size[vf-f]);
    cur_v ← cur_v + z;
    end;
    four_cases(xxx1): begin tmp_int ← packet_read_unsigned(cmd - xxx1 + 1); str_room(tmp_int);
    while tmp_int > 0 do
        begin decr(tmp_int); append_char(packet_byte);
        end;
    s ← make_string; literal(s, scan_special, false); flush_str(s);
    end;
    othercases pdf_error("vf", "invalid_DVI_command");
    endcases;
goto continue;
do_char: if is_valid_char(c) then output_one_char(c)
    else char_warning(f, c);
    if char_move then cur_h ← cur_h + char_width(f)(char_info(f)(c))

```

This code is used in section [725](#).

727. PDF shipping out. To ship out a TeX box to PDF page description we need to implement *pdf_hlist_out*, *pdf_vlist_out* and *pdf_ship_out*, which are equivalent to the TeX' original *hlist_out*, *vlist_out* and *ship_out* resp. But first we need to declare some procedures needed in *pdf_hlist_out* and *pdf_vlist_out*.

(Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727) \equiv

```

procedure pdf_out_literal(p : pointer);
  var old_setting: 0 .. max_selector; { holds print selector }
      s: str_number;
  begin old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string;
  show_token_list(link(pdf_literal_data(p)), null, pool_size - pool_ptr); selector  $\leftarrow$  old_setting;
  s  $\leftarrow$  make_string; literal(s, pdf_literal_mode(p), false); flush_str(s);
  end;

procedure pdf_out_colorstack(p : pointer);
  var old_setting: 0 .. max_selector; { holds print selector }
      s: str_number; cmd: integer; stack_no: integer; literal_mode: integer;
  begin cmd  $\leftarrow$  pdf_colorstack_cmd(p); stack_no  $\leftarrow$  pdf_colorstack_stack(p);
  if stack_no  $\geq$  colorstackused then
    begin print_nl(""); print("Color_stack"); print_int(stack_no);
    print("_is_not_initialized_for_use!"); print_nl(""); return;
    end;
  case cmd of
    colorstack_set, colorstack_push: begin old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string;
      show_token_list(link(pdf_colorstack_data(p)), null, pool_size - pool_ptr); selector  $\leftarrow$  old_setting;
      s  $\leftarrow$  make_string;
      if cmd = colorstack_set then literal_mode  $\leftarrow$  colorstackset(stack_no, s)
      else literal_mode  $\leftarrow$  colorstackpush(stack_no, s);
      if length(s) > 0 then literal(s, literal_mode, false);
      flush_str(s); return;
      end;
    colorstack_pop: literal_mode  $\leftarrow$  colorstackpop(stack_no);
    colorstack_current: literal_mode  $\leftarrow$  colorstackcurrent(stack_no);
  othercases confusion("pdfcolorstack")
  endcases;
  if cur_length > 0 then
    begin s  $\leftarrow$  make_string; literal(s, literal_mode, false); flush_str(s);
    end
  end;

procedure pdf_out_colorstack_startpage;
  var i: integer; max: integer; start_status: integer; literal_mode: integer; s: str_number;
  begin i  $\leftarrow$  0; max  $\leftarrow$  colorstackused;
  while i < max do
    begin start_status  $\leftarrow$  colorstackskippagestart(i);
    if start_status = 0 then
      begin literal_mode  $\leftarrow$  colorstackcurrent(i);
      if cur_length > 0 then
        begin s  $\leftarrow$  make_string; literal(s, literal_mode, false); flush_str(s);
        end;
      end;
      incr(i);
      end;
    end;

procedure pdf_out_setmatrix(p : pointer);
  var old_setting: 0 .. max_selector; { holds print selector }

```

```

    s: str_number;
begin old_setting ← selector; selector ← new_string;
show_token_list(link(pdf_setmatrix_data(p)), null, pool_size - pool_ptr); selector ← old_setting;
str_room(7); str_pool[pool_ptr] ← 0; { make C string for pdfsetmatrix }
if pdfsetmatrix(str_start[str_ptr], cur_h, cur_page_height - cur_v) = 1 then
    begin str_room(7); append_char("␣"); append_char("0"); append_char("␣"); append_char("0");
    append_char("␣"); append_char("c"); append_char("m"); s ← make_string; literal(s, set_origin, false);
    end
else begin pdf_error("\pdfsetmatrix", "Unrecognized_format.");
    end;
flush_str(s);
end;
procedure pdf_out_save(p: pointer);
    begin checkpdfsave(cur_h, cur_v); literal("q", set_origin, false);
    end;
procedure pdf_out_restore(p: pointer);
    begin checkpdfrestore(cur_h, cur_v); literal("Q", set_origin, false);
    end;
procedure pdf_special(p: pointer);
    var old_setting: 0 .. max_selector; { holds print selector }
    s: str_number;
    begin old_setting ← selector; selector ← new_string;
show_token_list(link(write_tokens(p)), null, pool_size - pool_ptr); selector ← old_setting;
s ← make_string; literal(s, scan_special, true); flush_str(s);
end;
procedure pdf_print_toks(p: pointer); { print tokens list p }
    var s: str_number;
    begin s ← tokens_to_string(p);
    if length(s) > 0 then pdf_print(s);
    flush_str(s);
    end;
procedure pdf_print_toks_ln(p: pointer); { print tokens list p }
    var s: str_number;
    begin s ← tokens_to_string(p);
    if length(s) > 0 then
        begin pdf_print_ln(s);
        end;
    flush_str(s);
    end;

```

See also sections 772, 778, 785, 1562, 1627, 1632, 1633, and 1634.

This code is used in section 729.

728. Similar to *vlist_out*, *pdf_vlist_out* needs to be declared forward.

```
procedure pdf_vlist_out; forward;
```

729. The implementation of procedure *pdf_hlist_out* is similar to *hlist_out*.

⟨Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727⟩

```
procedure pdf_hlist_out; { output an hlist_node box }
  label reswitch, move_past, fin_rule, next_p;
  var base_line: scaled; { the baseline coordinate for this box }
      left_edge: scaled; { the left coordinate for this box }
      save_h: scaled; { what cur_h should pop to }
      this_box: pointer; { pointer to containing box }
      g_order: glue_ord; { applicable order of infinity for glue }
      g_sign: normal .. shrinking; { selects type of glue }
      p: pointer; { current position in the hlist }
      leader_box: pointer; { the leader box being replicated }
      leader_wd: scaled; { width of leader box being replicated }
      lx: scaled; { extra space between leader boxes }
      outer_doing_leaders: boolean; { were we doing leaders? }
      edge: scaled; { right edge of sub-box or leader space }
      prev_p: pointer; { one step behind p }
      glue_temp: real; { glue value before rounding }
      cur_glue: real; { glue seen so far }
      cur_g: scaled; { rounded equivalent of cur_glue times the glue ratio }
      i: small_number; { index to scan pdf_link_stack }
  begin cur_g ← 0; cur_glue ← float_constant(0); this_box ← temp_ptr; g_order ← glue_order(this_box);
  g_sign ← glue_sign(this_box); p ← list_ptr(this_box); incr(cur_s); base_line ← cur_v;
  prev_p ← this_box + list_offset; ⟨Initialize hlist_out for mixed direction typesetting 1711⟩;
  left_edge ← cur_h; ⟨Create link annotations for the current hbox if needed 730⟩;
  while p ≠ null do ⟨Output node p for pdf_hlist_out and move to the next node, maintaining the
    condition cur_v = base_line 731⟩;
  ⟨Finish hlist_out for mixed direction typesetting 1712⟩;
  decr(cur_s);
end;
```

730. ⟨Create link annotations for the current hbox if needed 730⟩ ≡
for *i* ← 1 **to** *pdf_link_stack_ptr* **do**
 begin *pdfassert*(*is_running*(*pdf_width*(*pdf_link_stack*[*i*].*link_node*)));
 if (*pdf_link_stack*[*i*].*nesting_level* = *cur_s*) ∧ *gen_running_link* **then**
 append_link(*this_box*, *left_edge*, *base_line*, *i*);
 end

This code is used in section 729.

731. ⟨Output node *p* for *pdf_hlist_out* and move to the next node, maintaining the condition
cur_v = *base_line* 731⟩ ≡

```
reswitch: if is_char_node(p) then
  begin repeat f ← font(p); c ← character(p);
    if is_valid_char(c) then output_one_char(c)
    else char_warning(f, c);
    cur_h ← cur_h + char_width(f)(char_info(f)(c)); prev_p ← link(prev_p);
    { N.B.: not prev_p ← p, p might be lig_trick }
    p ← link(p);
  until ¬is_char_node(p);
end
else ⟨Output the non-char_node p for pdf_hlist_out and move to the next node 732⟩
```

This code is used in section 729.

732. \langle Output the non-*char_node* p for *pdf_hlist_out* and move to the next node 732 $\rangle \equiv$

```

begin case type( $p$ ) of
  hlist_node, vlist_node:  $\langle$  (pdfTeX) Output a box in an hlist 733  $\rangle$ ;
  rule_node: begin  $rule\_ht \leftarrow height(p)$ ;  $rule\_dp \leftarrow depth(p)$ ;  $rule\_wd \leftarrow width(p)$ ; goto fin_rule;
    end;
  whatsit_node:  $\langle$  Output the whatsit node  $p$  in pdf_hlist_out 1642  $\rangle$ ;
  glue_node:  $\langle$  (pdfTeX) Move right or output leaders 735  $\rangle$ ;
  margin_kern_node, kern_node:  $cur\_h \leftarrow cur\_h + width(p)$ ;
  math_node:  $\langle$  Handle a math node in hlist_out 1713  $\rangle$ ;
  ligature_node:  $\langle$  Make node  $p$  look like a char_node and goto reswitch 824  $\rangle$ ;
     $\langle$  Cases of hlist_out that arise in mixed direction text only 1717  $\rangle$ 
  othercases do_nothing
endcases;
goto next_p;
fin_rule:  $\langle$  (pdfTeX) Output a rule in an hlist 734  $\rangle$ ;
move_past:  $cur\_h \leftarrow cur\_h + rule\_wd$ ;
next_p:  $prev\_p \leftarrow p$ ;  $p \leftarrow link(p)$ ;
end
```

This code is used in section 731.

733. \langle (pdfTeX) Output a box in an hlist 733 $\rangle \equiv$

```

if list_ptr( $p$ ) = null then  $cur\_h \leftarrow cur\_h + width(p)$ 
else begin  $cur\_v \leftarrow base\_line + shift\_amount(p)$ ; { shift the box down }
   $temp\_ptr \leftarrow p$ ;  $edge \leftarrow cur\_h + width(p)$ ;
  if  $cur\_dir = right\_to\_left$  then  $cur\_h \leftarrow edge$ ;
  if type( $p$ ) = vlist_node then pdf_vlist_out else pdf_hlist_out;
   $cur\_h \leftarrow edge$ ;  $cur\_v \leftarrow base\_line$ ;
end
```

This code is used in section 732.

734. \langle (pdfTeX) Output a rule in an hlist 734 $\rangle \equiv$

```

if is_running( $rule\_ht$ ) then  $rule\_ht \leftarrow height(this\_box)$ ;
if is_running( $rule\_dp$ ) then  $rule\_dp \leftarrow depth(this\_box)$ ;
 $rule\_ht \leftarrow rule\_ht + rule\_dp$ ; { this is the rule thickness }
if ( $rule\_ht > 0$ )  $\wedge$  ( $rule\_wd > 0$ ) then { we don't output empty rules }
  begin  $cur\_v \leftarrow base\_line + rule\_dp$ ; pdf_set_rule( $cur\_h$ ,  $cur\_v$ ,  $rule\_wd$ ,  $rule\_ht$ );  $cur\_v \leftarrow base\_line$ ;
  end
```

This code is used in section 732.

```

735.  ⟨(pdfTeX) Move right or output leaders 735⟩ ≡
begin  $g \leftarrow glue\_ptr(p)$ ;  $rule\_wd \leftarrow width(g) - cur\_g$ ;
if  $g\_sign \neq normal$  then
  begin if  $g\_sign = stretching$  then
    begin if  $stretch\_order(g) = g\_order$  then
      begin  $cur\_glue \leftarrow cur\_glue + stretch(g)$ ;  $vet\_glue(float(glue\_set(this\_box)) * cur\_glue)$ ;
       $cur\_g \leftarrow round(glue\_temp)$ ;
      end;
    end
  else if  $shrink\_order(g) = g\_order$  then
    begin  $cur\_glue \leftarrow cur\_glue - shrink(g)$ ;  $vet\_glue(float(glue\_set(this\_box)) * cur\_glue)$ ;
     $cur\_g \leftarrow round(glue\_temp)$ ;
    end;
  end;
 $rule\_wd \leftarrow rule\_wd + cur\_g$ ;
if  $eTeX\_ex$  then ⟨Handle a glue node for mixed direction typesetting 1696⟩;
if  $subtype(p) \geq a\_leaders$  then
  ⟨(pdfTeX) Output leaders in an hlist, goto  $fin\_rule$  if a rule or to  $next\_p$  if done 736⟩;
goto  $move\_past$ ;
end

```

This code is used in section 732.

```

736.  ⟨(pdfTeX) Output leaders in an hlist, goto  $fin\_rule$  if a rule or to  $next\_p$  if done 736⟩ ≡
begin  $leader\_box \leftarrow leader\_ptr(p)$ ;
if  $type(leader\_box) = rule\_node$  then
  begin  $rule\_ht \leftarrow height(leader\_box)$ ;  $rule\_dp \leftarrow depth(leader\_box)$ ; goto  $fin\_rule$ ;
  end;
 $leader\_wd \leftarrow width(leader\_box)$ ;
if  $(leader\_wd > 0) \wedge (rule\_wd > 0)$  then
  begin  $rule\_wd \leftarrow rule\_wd + 10$ ; {compensate for floating-point rounding}
  if  $cur\_dir = right\_to\_left$  then  $cur\_h \leftarrow cur\_h - 10$ ;
   $edge \leftarrow cur\_h + rule\_wd$ ;  $lx \leftarrow 0$ ; ⟨Let  $cur\_h$  be the position of the first box, and set  $leader\_wd + lx$  to
  the spacing between corresponding parts of boxes 655⟩;
  while  $cur\_h + leader\_wd \leq edge$  do
    ⟨(pdfTeX) Output a leader box at  $cur\_h$ , then advance  $cur\_h$  by  $leader\_wd + lx$  737⟩;
    if  $cur\_dir = right\_to\_left$  then  $cur\_h \leftarrow edge$ 
    else  $cur\_h \leftarrow edge - 10$ ;
    goto  $next\_p$ ;
  end;
end

```

This code is used in section 735.

```

737.  ⟨(pdfTeX) Output a leader box at  $cur\_h$ , then advance  $cur\_h$  by  $leader\_wd + lx$  737⟩ ≡
begin  $cur\_v \leftarrow base\_line + shift\_amount(leader\_box)$ ;
 $save\_h \leftarrow cur\_h$ ;  $temp\_ptr \leftarrow leader\_box$ ;
if  $cur\_dir = right\_to\_left$  then  $cur\_h \leftarrow cur\_h + leader\_wd$ ;
 $outer\_doing\_leaders \leftarrow doing\_leaders$ ;  $doing\_leaders \leftarrow true$ ;
if  $type(leader\_box) = vlist\_node$  then  $pdf\_vlist\_out$  else  $pdf\_hlist\_out$ ;
 $doing\_leaders \leftarrow outer\_doing\_leaders$ ;  $cur\_v \leftarrow base\_line$ ;  $cur\_h \leftarrow save\_h + leader\_wd + lx$ ;
end

```

This code is used in section 736.

738. The *pdf_vlist_out* routine is similar to *pdf_hlist_out*, but a bit simpler.

```
procedure pdf_vlist_out; { output a pdf_vlist_node box }
label move_past, fin_rule, next_p;
var left_edge: scaled; { the left coordinate for this box }
    top_edge: scaled; { the top coordinate for this box }
    save_v: scaled; { what cur_v should pop to }
    this_box: pointer; { pointer to containing box }
    g_order: glue_ord; { applicable order of infinity for glue }
    g_sign: normal .. shrinking; { selects type of glue }
    p: pointer; { current position in the vlist }
    leader_box: pointer; { the leader box being replicated }
    leader_ht: scaled; { height of leader box being replicated }
    lx: scaled; { extra space between leader boxes }
    outer_doing_leaders: boolean; { were we doing leaders? }
    edge: scaled; { bottom boundary of leader space }
    glue_temp: real; { glue value before rounding }
    cur_glue: real; { glue seen so far }
    cur_g: scaled; { rounded equivalent of cur_glue times the glue ratio }
begin cur_g ← 0; cur_glue ← float_constant(0); this_box ← temp_ptr; g_order ← glue_order(this_box);
    g_sign ← glue_sign(this_box); p ← list_ptr(this_box); incr(cur_s); left_edge ← cur_h;
    cur_v ← cur_v - height(this_box); top_edge ← cur_v; ⟨ Create thread for the current vbox if needed 739 ⟩;
while p ≠ null do ⟨ Output node p for pdf_vlist_out and move to the next node, maintaining the
    condition cur_h = left_edge 740 ⟩;
    decr(cur_s);
end;
```

739. ⟨ Create thread for the current vbox if needed 739 ⟩ ≡
if (last_thread ≠ null) ∧ is_running(pdf_thread_dp) ∧ (pdf_thread_level = cur_s) **then**
 append_thread(this_box, left_edge, top_edge + height(this_box))

This code is used in section 738.

740. ⟨ Output node p for pdf_vlist_out and move to the next node, maintaining the condition
 cur_h = left_edge 740 ⟩ ≡
begin if is_char_node(p) **then** confusion("pdfvlistout")
else ⟨ Output the non-char_node p for pdf_vlist_out 741 ⟩;
 next_p: p ← link(p);
end

This code is used in section 738.

741. \langle Output the non-*char_node* p for *pdf_vlist_out* 741 $\rangle \equiv$

```

begin case type( $p$ ) of
  hlist_node, vlist_node:  $\langle$  (pdfTeX) Output a box in a vlist 742  $\rangle$ ;
  rule_node: begin rule_ht  $\leftarrow$  height( $p$ ); rule_dp  $\leftarrow$  depth( $p$ ); rule_wd  $\leftarrow$  width( $p$ ); goto fin_rule;
    end;
  whatsit_node:  $\langle$  Output the whatsit node  $p$  in pdf_vlist_out 1636  $\rangle$ ;
  glue_node:  $\langle$  (pdfTeX) Move down or output leaders 744  $\rangle$ ;
  kern_node: cur_v  $\leftarrow$  cur_v + width( $p$ );
  othercases do_nothing
endcases;
goto next_p;
fin_rule:  $\langle$  (pdfTeX) Output a rule in a vlist, goto next_p 743  $\rangle$ ;
move_past: cur_v  $\leftarrow$  cur_v + rule_ht;
end

```

This code is used in section 740.

742. \langle (pdfTeX) Output a box in a vlist 742 $\rangle \equiv$

```

if list_ptr( $p$ ) = null then cur_v  $\leftarrow$  cur_v + height( $p$ ) + depth( $p$ )
else begin cur_v  $\leftarrow$  cur_v + height( $p$ ); save_v  $\leftarrow$  cur_v;
  if cur_dir = right_to_left then cur_h  $\leftarrow$  left_edge - shift_amount( $p$ )
  else cur_h  $\leftarrow$  left_edge + shift_amount( $p$ ); { shift the box right }
  temp_ptr  $\leftarrow$   $p$ ;
  if type( $p$ ) = vlist_node then pdf_vlist_out else pdf_hlist_out;
  cur_v  $\leftarrow$  save_v + depth( $p$ ); cur_h  $\leftarrow$  left_edge;
end

```

This code is used in section 741.

743. \langle (pdfTeX) Output a rule in a vlist, **goto** *next_p* 743 $\rangle \equiv$

```

if is_running(rule_wd) then rule_wd  $\leftarrow$  width(this_box);
rule_ht  $\leftarrow$  rule_ht + rule_dp; { this is the rule thickness }
cur_v  $\leftarrow$  cur_v + rule_ht;
if (rule_ht > 0)  $\wedge$  (rule_wd > 0) then { we don't output empty rules }
  begin if cur_dir = right_to_left then cur_h  $\leftarrow$  cur_h - rule_wd;
  pdf_set_rule(cur_h, cur_v, rule_wd, rule_ht); cur_h  $\leftarrow$  left_edge;
  end;
goto next_p

```

This code is used in section 741.

744. $\langle (\text{pdfTeX}) \text{ Move down or output leaders } 744 \rangle \equiv$

```

begin  $g \leftarrow \text{glue\_ptr}(p)$ ;  $\text{rule\_ht} \leftarrow \text{width}(g) - \text{cur\_g}$ ;
if  $g\_sign \neq \text{normal}$  then
  begin if  $g\_sign = \text{stretching}$  then
    begin if  $\text{stretch\_order}(g) = g\_order$  then
      begin  $\text{cur\_glue} \leftarrow \text{cur\_glue} + \text{stretch}(g)$ ;  $\text{vet\_glue}(\text{float}(\text{glue\_set}(\text{this\_box})) * \text{cur\_glue})$ ;
       $\text{cur\_g} \leftarrow \text{round}(\text{glue\_temp})$ ;
      end;
    end
  else if  $\text{shrink\_order}(g) = g\_order$  then
    begin  $\text{cur\_glue} \leftarrow \text{cur\_glue} - \text{shrink}(g)$ ;  $\text{vet\_glue}(\text{float}(\text{glue\_set}(\text{this\_box})) * \text{cur\_glue})$ ;
     $\text{cur\_g} \leftarrow \text{round}(\text{glue\_temp})$ ;
    end;
  end;
 $\text{rule\_ht} \leftarrow \text{rule\_ht} + \text{cur\_g}$ ;
if  $\text{subtype}(p) \geq a\_leaders$  then
   $\langle (\text{pdfTeX}) \text{ Output leaders in a vlist, goto } \text{fin\_rule} \text{ if a rule or to } \text{next\_p} \text{ if done } 745 \rangle$ ;
goto  $\text{move\_past}$ ;
end

```

This code is used in section 741.

745. $\langle (\text{pdfTeX}) \text{ Output leaders in a vlist, goto } \text{fin_rule} \text{ if a rule or to } \text{next_p} \text{ if done } 745 \rangle \equiv$

```

begin  $\text{leader\_box} \leftarrow \text{leader\_ptr}(p)$ ;
if  $\text{type}(\text{leader\_box}) = \text{rule\_node}$  then
  begin  $\text{rule\_wd} \leftarrow \text{width}(\text{leader\_box})$ ;  $\text{rule\_dp} \leftarrow 0$ ; goto  $\text{fin\_rule}$ ;
end;
 $\text{leader\_ht} \leftarrow \text{height}(\text{leader\_box}) + \text{depth}(\text{leader\_box})$ ;
if  $(\text{leader\_ht} > 0) \wedge (\text{rule\_ht} > 0)$  then
  begin  $\text{rule\_ht} \leftarrow \text{rule\_ht} + 10$ ; { compensate for floating-point rounding }
   $\text{edge} \leftarrow \text{cur\_v} + \text{rule\_ht}$ ;  $\text{lx} \leftarrow 0$ ;  $\langle \text{Let } \text{cur\_v} \text{ be the position of the first box, and set } \text{leader\_ht} + \text{lx} \text{ to}$ 
    the spacing between corresponding parts of boxes 664  $\rangle$ ;
  while  $\text{cur\_v} + \text{leader\_ht} \leq \text{edge}$  do
     $\langle (\text{pdfTeX}) \text{ Output a leader box at } \text{cur\_v}$ , then advance  $\text{cur\_v}$  by  $\text{leader\_ht} + \text{lx}$  746  $\rangle$ ;
     $\text{cur\_v} \leftarrow \text{edge} - 10$ ; goto  $\text{next\_p}$ ;
  end;
end

```

This code is used in section 744.

746. $\langle (\text{pdfTeX}) \text{ Output a leader box at } \text{cur_v}$, then advance cur_v by $\text{leader_ht} + \text{lx}$ 746 $\rangle \equiv$

```

begin if  $\text{cur\_dir} = \text{right\_to\_left}$  then  $\text{cur\_h} \leftarrow \text{left\_edge} - \text{shift\_amount}(\text{leader\_box})$ 
else  $\text{cur\_h} \leftarrow \text{left\_edge} + \text{shift\_amount}(\text{leader\_box})$ ;
 $\text{cur\_v} \leftarrow \text{cur\_v} + \text{height}(\text{leader\_box})$ ;  $\text{save\_v} \leftarrow \text{cur\_v}$ ;  $\text{temp\_ptr} \leftarrow \text{leader\_box}$ ;
 $\text{outer\_doing\_leaders} \leftarrow \text{doing\_leaders}$ ;  $\text{doing\_leaders} \leftarrow \text{true}$ ;
if  $\text{type}(\text{leader\_box}) = \text{vlist\_node}$  then  $\text{pdf\_vlist\_out}$  else  $\text{pdf\_hlist\_out}$ ;
 $\text{doing\_leaders} \leftarrow \text{outer\_doing\_leaders}$ ;  $\text{cur\_h} \leftarrow \text{left\_edge}$ ;
 $\text{cur\_v} \leftarrow \text{save\_v} - \text{height}(\text{leader\_box}) + \text{leader\_ht} + \text{lx}$ ;
end

```

This code is used in section 745.

747. *fix_pdfoutput* freezes *pdfoutput* when something has been written to the output.

```

procedure fix_pdfoutput;
  begin if  $\neg$ fixed_pdfoutput_set then
    begin fixed_pdfoutput  $\leftarrow$  pdf_output; fixed_pdfoutput_set  $\leftarrow$  true;
    end
  else if fixed_pdfoutput  $\neq$  pdf_output then pdf_error("setup",
    "\pdfoutput can only be changed before anything is written to the output");
  if fixed_pdfoutput_set then fix_pdf_draftmode;
  end;

```

748. *fix_pdf_draftmode* freezes *pdfdraftmode* when something has been written to the output and also switches some things off when draftmode is on.

```

procedure fix_pdf_draftmode;
  begin if  $\neg$ fixed_pdf_draftmode_set then
    begin fixed_pdf_draftmode  $\leftarrow$  pdf_draftmode; fixed_pdf_draftmode_set  $\leftarrow$  true;
    end
  else if fixed_pdf_draftmode  $\neq$  pdf_draftmode then pdf_error("setup",
    "\pdfdraftmode can only be changed before anything is written to the output");
  if fixed_pdf_draftmode_set  $\wedge$  fixed_pdf_draftmode  $>$  0 then
    begin fixed_pdf_draftmode_set  $\leftarrow$  true; pdf_compress_level  $\leftarrow$  0; fixed_pdf_objcompresslevel  $\leftarrow$  0;
    end;
  end;

```

749. *substr_of_str* is used in *pdf_ship_out* and *pdf_print_info*.

```

function substr_of_str(s, t : str_number): boolean;
  label continue, exit;
  var j, k, kk: pool_pointer; { running indices }
  begin k  $\leftarrow$  str_start[t];
  while (k  $<$  str_start[t + 1] - length(s)) do
    begin j  $\leftarrow$  str_start[s]; kk  $\leftarrow$  k;
    while (j  $<$  str_start[s + 1]) do
      begin if str_pool[j]  $\neq$  str_pool[kk] then goto continue;
      incr(j); incr(kk);
      end;
    substr_of_str  $\leftarrow$  true; return;
  continue: incr(k);
  end;
  substr_of_str  $\leftarrow$  false;
end;

```

750. *pdf_ship_out* is used instead of *ship_out* to shipout a box to PDF output. If *shipping_page* is not set then the output will be a Form object, otherwise it will be a Page object.

```

procedure pdf_ship_out(p : pointer; shipping_page : boolean); { output the box p }
  label done, done1;
  var i, j, k: integer; { general purpose accumulators }
      s: pool_pointer; { index into str_pool }
      mediabox_given: boolean; save_font_list: pointer;
          { to save pdf_font_list during flushing pending forms }
      save_obj_list: pointer; { to save pdf_obj_list }
      save_ximage_list: pointer; { to save pdf_ximage_list }
      save_xform_list: pointer; { to save pdf_xform_list }
      save_image_procset: integer; { to save pdf_image_procset }
      save_text_procset: integer; { to save pdf_text_procset }
      pdf_last_resources: integer; { pointer to most recently generated Resources object }
  begin if tracing_output > 0 then
    begin print_nl(""); print_ln; print("Completed_box_being_shipped_out");
    end;
  if  $\neg$ init_pdf_output then
    begin  $\langle$  Initialize variables for PDF output 792  $\rangle$ ;
    init_pdf_output  $\leftarrow$  true;
    end;
  is_shipping_page  $\leftarrow$  shipping_page;
  if shipping_page then
    begin if term_offset > max_print_line - 9 then print_ln
    else if (term_offset > 0)  $\vee$  (file_offset > 0) then print_char(" ");
    print_char("["); j  $\leftarrow$  9;
    while (count(j) = 0)  $\wedge$  (j > 0) do decr(j);
    for k  $\leftarrow$  0 to j do
      begin print_int(count(k));
      if k < j then print_char(".");
      end;
    update_terminal;
    end;
  if tracing_output > 0 then
    begin if shipping_page then print_char("");
    begin_diagnostic; show_box(p); end_diagnostic(true);
    end;
   $\langle$  (pdfTeX) Ship box p out 751  $\rangle$ ;
  if eTeX_ex then  $\langle$  Check for LR anomalies at the end of ship_out 1727  $\rangle$ ;
  if (tracing_output  $\leq$  0)  $\wedge$  shipping_page then print_char("");
  dead_cycles  $\leftarrow$  0; update_terminal; { progress report }
   $\langle$  Flush the box from memory, showing statistics if requested 667  $\rangle$ ;
  end;

```

751. \langle (pdfTeX) Ship box *p* out 751 $\rangle \equiv$
 \langle Update the values of *max_h* and *max_v*; but if the page is too large, **goto** *done* 669 \rangle ;
 \langle Initialize variables as *pdf_ship_out* begins 752 \rangle ;
if *type*(*p*) = *vlist_node* **then** *pdf_vlist_out* **else** *pdf_hlist_out*;
if *shipping_page* **then** *incr*(*total_pages*);
cur_s \leftarrow -1; \langle Finish shipping 759 \rangle ;

done:

This code is used in section 750.

752. \langle Initialize variables as *pdf_ship_out* begins 752 $\rangle \equiv$
fix_pdfoutput; *temp_ptr* \leftarrow *p*; *prepare_mag*; *pdf_last_resources* \leftarrow *pdf_new_objnum*;
pdf_page_group_val \leftarrow 0; \langle Reset resource lists 753 \rangle ;
if \neg *shipping_page* **then**
 begin *pdf_xform_width* \leftarrow *width*(*p*); *pdf_xform_height* \leftarrow *height*(*p*); *pdf_xform_depth* \leftarrow *depth*(*p*);
 pdf_begin_dict(*pdf_cur_form*, 0); *pdf_last_stream* \leftarrow *pdf_cur_form*; *cur_v* \leftarrow *height*(*p*); *cur_h* \leftarrow 0;
 pdf_origin_h \leftarrow 0; *pdf_origin_v* \leftarrow *pdf_xform_height* + *pdf_xform_depth*;
 end
else begin \langle Calculate page dimensions and margins 755 \rangle ;
 pdf_last_page \leftarrow *get_obj*(*obj_type_page*, *total_pages* + 1, 0); *obj_aux*(*pdf_last_page*) \leftarrow 1;
 { mark that this page has been created }
 pdf_new_dict(*obj_type_others*, 0, 0); *pdf_last_stream* \leftarrow *obj_ptr*; *cur_h* \leftarrow *cur_h_offset*;
 cur_v \leftarrow *height*(*p*) + *cur_v_offset*; *pdf_origin_h* \leftarrow 0; *pdf_origin_v* \leftarrow *cur_page_height*;
 \langle Reset PDF mark lists 754 \rangle ;
 end;
if \neg *shipping_page* **then**
 begin \langle Write out Form stream header 756 \rangle ;
 end;
 \langle Start stream of page/form contents 757 \rangle

This code is used in section 751.

753. \langle Reset resource lists 753 $\rangle \equiv$
pdf_font_list \leftarrow *null*; *pdf_obj_list* \leftarrow *null*; *pdf_xform_list* \leftarrow *null*; *pdf_ximage_list* \leftarrow *null*;
pdf_text_procset \leftarrow *false*; *pdf_image_procset* \leftarrow 0

This code is used in sections 752 and 775.

754. \langle Reset PDF mark lists 754 $\rangle \equiv$
pdf_annot_list \leftarrow *null*; *pdf_link_list* \leftarrow *null*; *pdf_dest_list* \leftarrow *null*; *pdf_bead_list* \leftarrow *null*; *last_thread* \leftarrow *null*

This code is used in section 752.

755. \langle Calculate page dimensions and margins 755 $\rangle \equiv$
cur_h_offset \leftarrow *pdf_h_origin* + *h_offset*; *cur_v_offset* \leftarrow *pdf_v_origin* + *v_offset*;
if *pdf_page_width* \neq 0 **then** *cur_page_width* \leftarrow *pdf_page_width*
else *cur_page_width* \leftarrow *width*(*p*) + 2 * *cur_h_offset*;
if *pdf_page_height* \neq 0 **then** *cur_page_height* \leftarrow *pdf_page_height*
else *cur_page_height* \leftarrow *height*(*p*) + *depth*(*p*) + 2 * *cur_v_offset*

This code is used in section 752.

756. Here we write out the header for Form.

\langle Write out Form stream header 756 $\rangle \equiv$
pdf_print_ln("/Type_ XObject"); *pdf_print_ln*("/Subtype_ Form");
if *obj_xform_attr*(*pdf_cur_form*) \neq *null* **then**
 begin *pdf_print_toks_ln*(*obj_xform_attr*(*pdf_cur_form*)); *delete_toks*(*obj_xform_attr*(*pdf_cur_form*));
 end;
pdf_print("/BBox_ ["); *pdf_print*("0_0_"); *pdf_print_bp*(*pdf_xform_width*); *pdf_out*("_");
pdf_print_bp(*pdf_xform_height* + *pdf_xform_depth*); *pdf_print_ln*("]"); *pdf_print_ln*("/FormType_ 1");
pdf_print_ln("/Matrix_ [1_0_0_1_0_0_]"); *pdf_indirect_ln*("Resources", *pdf_last_resources*)

This code is used in section 752.

757. \langle Start stream of page/form contents 757 $\rangle \equiv$
pdf_begin_stream;
if *shipping_page* **then**
 begin \langle Adjust transformation matrix for the magnification ratio 758 \rangle ;
 end;
 pdfshipoutbegin(*shipping_page*);
if *shipping_page* **then** *pdf_out_colorstack_startpage*;

This code is used in section 752.

758. \langle Adjust transformation matrix for the magnification ratio 758 $\rangle \equiv$
prepare_mag;
if *mag* \neq 1000 **then**
 begin *pdf_print_real*(*mag*, 3); *pdf_print*("_0_0_"); *pdf_print_real*(*mag*, 3); *pdf_print_ln*("_0_0_cm");
 end

This code is used in section 757.

759. \langle Finish shipping 759 $\rangle \equiv$
 \langle Finish stream of page/form contents 760 \rangle ;
if *shipping_page* **then**
 begin \langle Write out page object 769 \rangle ;
 end;
 \langle Write out resource lists 761 \rangle ;
if *shipping_page* **then**
 begin \langle Write out pending PDF marks 780 \rangle ;
 end;
 \langle Write out resources dictionary 762 \rangle ;
 \langle Flush resource lists 764 \rangle ;
if *shipping_page* **then**
 begin \langle Flush PDF mark lists 765 \rangle ;
 end

This code is used in section 751.

760. \langle Finish stream of page/form contents 760 $\rangle \equiv$
pdf_end_text; *pdfshipoutend*(*shipping_page*); *pdf_end_stream*

This code is used in section 759.

761. \langle Write out resource lists 761 $\rangle \equiv$
 \langle Write out pending raw objects 773 \rangle ;
 \langle Write out pending forms 775 \rangle ;
 \langle Write out pending images 779 \rangle

This code is used in section 759.

762. \langle Write out resources dictionary 762 $\rangle \equiv$
pdf_begin_dict(*pdf_last_resources*, 1); \langle Print additional resources 763 \rangle ;
 \langle Generate font resources 766 \rangle ;
 \langle Generate XObject resources 767 \rangle ;
 \langle Generate ProcSet 768 \rangle ;
pdf_end_dict

This code is used in section 759.

```

763.  ⟨ Print additional resources 763 ⟩ ≡
  if shipping-page then
    begin if pdf-page-resources ≠ null then pdf-print-toks.ln(pdf-page-resources);
    end
  else begin if obj_xform-resources(pdf_cur_form) ≠ null then
    begin pdf-print-toks.ln(obj_xform-resources(pdf_cur_form));
    delete_toks(obj_xform-resources(pdf_cur_form));
    end;
  end

```

This code is used in section 762.

764. In the end of shipping out a page we reset all the lists holding objects have been created during the page shipping.

```

  define delete_toks(#) ≡
    begin delete_token_ref(#); # ← null;
    end
  ⟨ Flush resource lists 764 ⟩ ≡
    flush_list(pdf-font-list); flush_list(pdf-obj-list); flush_list(pdf-xform-list); flush_list(pdf-ximage-list)

```

This code is used in section 759.

```

765.  ⟨ Flush PDF mark lists 765 ⟩ ≡
    flush_list(pdf-annot-list); flush_list(pdf-link-list); flush_list(pdf-dest-list); flush_list(pdf-bead-list)

```

This code is used in section 759.

```

766.  ⟨ Generate font resources 766 ⟩ ≡
  if pdf-font-list ≠ null then
    begin pdf_print("/Font_<<_"); k ← pdf-font-list;
    while k ≠ null do
      begin pdf_print("/F"); set_ff(info(k)); pdf_print_int(ff); pdf_print_resname_prefix; pdf_out("_");
      pdf_print_int(pdf-font-num[ff]); pdf_print("_O_R_"); k ← link(k);
      end;
    pdf_print_ln(">>"); pdf_text_procset ← true;
  end

```

This code is used in section 762.

```

767.  ⟨ GenerateXObject resources 767 ⟩ ≡
  if (pdf-xform-list ≠ null) ∨ (pdf-ximage-list ≠ null) then
    begin pdf_print("/XObject_<<_"); k ← pdf-xform-list;
    while k ≠ null do
      begin pdf_print("/Fm"); pdf_print_int(obj_info(info(k))); pdf_print_resname_prefix; pdf_out("_");
      pdf_print_int(info(k)); pdf_print("_O_R_"); k ← link(k);
      end;
    k ← pdf-ximage-list;
    while k ≠ null do
      begin pdf_print("/Im"); pdf_print_int(obj_info(info(k))); pdf_print_resname_prefix; pdf_out("_");
      pdf_print_int(info(k)); pdf_print("_O_R_"); update_image_procset(obj-ximage-data(info(k)));
      k ← link(k);
      end;
    pdf_print_ln(">>");
  end

```

This code is used in section 762.

768. $\langle \text{Generate ProcSet 768} \rangle \equiv$

```
pdf_print("/ProcSet_[]/PDF");
if pdf_text_procset then pdf_print("_/Text");
if check_image_b(pdf_image_procset) then pdf_print("_/ImageB");
if check_image_c(pdf_image_procset) then pdf_print("_/ImageC");
if check_image_i(pdf_image_procset) then pdf_print("_/ImageI");
pdf_print_ln("_"]")
```

This code is used in section 762.

769. $\langle \text{Write out page object 769} \rangle \equiv$

```
pdf_begin_dict(pdf_last_page, 1); pdf_print_ln("/Type_/Page");
pdf_indirect_ln("Contents", pdf_last_stream); pdf_indirect_ln("Resources", pdf_last_resources);
mediabox_given ← false;
if pdf_page_attr ≠ null then
  begin s ← tokens_to_string(pdf_page_attr); mediabox_given ← substr_of_str("/MediaBox", s);
  flush_str(s);
end;
if ¬mediabox_given then
  begin pdf_print("/MediaBox_[0_0_]"); pdf_print_mag_bp(cur_page_width); pdf_out("_");
  pdf_print_mag_bp(cur_page_height); pdf_print_ln("]");
end;
if pdf_page_attr ≠ null then pdf_print_toks_ln(pdf_page_attr);
⟨Generate parent pages object 770⟩;
if pdf_page_group_val > 0 then
  begin pdf_print("/Group_"); pdf_print_int(pdf_page_group_val); pdf_print_ln("_0_R");
end;
⟨Generate array of annotations or beads in page 771⟩;
pdf_end_dict
```

This code is used in section 759.

770. $\langle \text{Generate parent pages object 770} \rangle \equiv$

```
if total_pages mod pages_tree_kids_max = 1 then
  begin pdf_create_obj(obj_type_pages, pages_tree_kids_max); pdf_last_pages ← obj_ptr;
end;
pdf_indirect_ln("Parent", pdf_last_pages)
```

This code is used in section 769.

771. $\langle \text{Generate array of annotations or beads in page 771} \rangle \equiv$

```

if (pdf_annot_list  $\neq$  null)  $\vee$  (pdf_link_list  $\neq$  null) then
  begin pdf_print("/Annots□□"); k  $\leftarrow$  pdf_annot_list;
  while k  $\neq$  null do
    begin pdf_print_int(info(k)); pdf_print("□O□R□"); k  $\leftarrow$  link(k);
    end;
  k  $\leftarrow$  pdf_link_list;
  while k  $\neq$  null do
    begin pdf_print_int(info(k)); pdf_print("□O□R□"); k  $\leftarrow$  link(k);
    end;
  pdf_print_ln("□");
  end;
if pdf_bead_list  $\neq$  null then
  begin k  $\leftarrow$  pdf_bead_list; pdf_print("/B□□");
  while k  $\neq$  null do
    begin pdf_print_int(info(k)); pdf_print("□O□R□"); k  $\leftarrow$  link(k);
    end;
  pdf_print_ln("□");
  end

```

This code is used in section 769.

772. \langle Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727 $\rangle + \equiv$

```

procedure pdf_write_obj(n : integer); { write a raw PDF object }
  var s: str_number; f: byte_file;
  begin s ← tokens_to_string(obj_obj_data(n)); delete_toks(obj_obj_data(n));
  if obj_obj_is_stream(n) > 0 then
    begin pdf_begin_dict(n, 0);
    if obj_obj_stream_attr(n) ≠ null then
      begin pdf_print_toks_ln(obj_obj_stream_attr(n)); delete_toks(obj_obj_stream_attr(n));
      end;
    pdf_begin_stream;
  end
  else pdf_begin_obj(n, 1);
  if obj_obj_is_file(n) > 0 then
    begin cur_name ← s; cur_area ← ""; cur_ext ← ""; pack_cur_name;
    if ¬tex_b_openin(f) then
      begin print_nl("!"); print(s); print("_not_found.");
      pdf_error("ext5", "cannot_open_file_for_embedding");
      end;
    print("<<"); print(s);
    if ¬eof(f) then
      begin { at least one byte available }
      while ¬eof(f) do pdf_out(getc(f));
      if (¬obj_obj_is_stream(n) ∧ (pdf_ptr > 0) ∧ (pdf_buf[pdf_ptr - 1] ≠ 10) then pdf_out(10);
      end;
    print(">>"); b_close(f);
  end
  else if obj_obj_is_stream(n) > 0 then pdf_print(s)
  else pdf_print_ln(s);
  if obj_obj_is_stream(n) > 0 then pdf_end_stream
  else pdf_end_obj;
  flush_str(s);
  end;
procedure flush_whatsit_node(p : pointer; s : small_number);
  begin type(p) ← whatsit_node; subtype(p) ← s;
  if link(p) ≠ null then pdf_error("flush_whatsit_node", "link(p)_is_not_null");
  flush_node_list(p);
  end;

```

773. \langle Write out pending raw objects 773 $\rangle \equiv$

```

if pdf_obj_list ≠ null then
  begin k ← pdf_obj_list;
  while k ≠ null do
    begin if ¬is_obj_written(info(k)) then pdf_write_obj(info(k));
    k ← link(k);
    end;
  end

```

This code is used in section 761.

774. \langle Global variables 13 $\rangle + \equiv$

saved_pdf_cur_form: integer;

775. When flushing pending forms we need to save and restore resource lists (*pdf_font_list*, *pdf_obj_list*, *pdf_xform_list* and *pdf_ximage_list*), which are also used by page shipping.

```

< Write out pending forms 775 > ≡
  if pdf_xform_list ≠ null then
    begin k ← pdf_xform_list;
    while k ≠ null do
      begin if ¬is_obj_written(info(k)) then
        begin saved_pdf_cur_form ← pdf_cur_form; pdf_cur_form ← info(k); < Save resource lists 776 >;
        < Reset resource lists 753 >;
        pdf_ship_out(obj_xform_box(pdf_cur_form), false); pdf_cur_form ← saved_pdf_cur_form;
        < Restore resource lists 777 >;
        end;
        k ← link(k);
      end;
    end
  end

```

This code is used in section 761.

```

776. < Save resource lists 776 > ≡
  save_font_list ← pdf_font_list; save_obj_list ← pdf_obj_list; save_xform_list ← pdf_xform_list;
  save_ximage_list ← pdf_ximage_list; save_text_procset ← pdf_text_procset;
  save_image_procset ← pdf_image_procset

```

This code is used in section 775.

```

777. < Restore resource lists 777 > ≡
  pdf_font_list ← save_font_list; pdf_obj_list ← save_obj_list; pdf_xform_list ← save_xform_list;
  pdf_ximage_list ← save_ximage_list; pdf_text_procset ← save_text_procset;
  pdf_image_procset ← save_image_procset

```

This code is used in section 775.

778. < Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727 > +≡

```

procedure pdf_write_image(n : integer); { write an image }
  begin pdf_begin_dict(n, 0);
  if obj_ximage_attr(n) ≠ null then
    begin pdf_print_toks_ln(obj_ximage_attr(n)); delete_toks(obj_ximage_attr(n));
    end;
  if fixed_pdf_draftmode = 0 then write_image(obj_ximage_data(n));
  delete_image(obj_ximage_data(n));
  end;

```

779. < Write out pending images 779 > ≡

```

if pdf_ximage_list ≠ null then
  begin k ← pdf_ximage_list;
  while k ≠ null do
    begin if ¬is_obj_written(info(k)) then pdf_write_image(info(k));
    k ← link(k);
    end;
  end

```

This code is used in section 761.

780. \langle Write out pending PDF marks 780 $\rangle \equiv$

```
pdf_origin_h  $\leftarrow$  0; pdf_origin_v  $\leftarrow$  cur_page_height;  $\langle$  Write out PDF annotations 781  $\rangle$ ;
 $\langle$  Write out PDF link annotations 782  $\rangle$ ;
 $\langle$  Write out PDF mark destinations 784  $\rangle$ ;
 $\langle$  Write out PDF bead rectangle specifications 786  $\rangle$ 
```

This code is used in section 759.

781. \langle Write out PDF annotations 781 $\rangle \equiv$

```
if pdf_annot_list  $\neq$  null then
  begin k  $\leftarrow$  pdf_annot_list;
  while k  $\neq$  null do
    begin i  $\leftarrow$  obj_annot_ptr(info(k)); { i points to pdf_annot_node }
    pdf_begin_dict(info(k), 1); pdf_print_ln("/Type_□/Annot"); pdf_print_toks_ln(pdf_annot_data(i));
    pdf_rectangle(pdf_left(i), pdf_top(i), pdf_right(i), pdf_bottom(i)); pdf_end_dict; k  $\leftarrow$  link(k);
    end;
  end
```

This code is used in section 780.

782. \langle Write out PDF link annotations 782 $\rangle \equiv$

```
if pdf_link_list  $\neq$  null then
  begin k  $\leftarrow$  pdf_link_list;
  while k  $\neq$  null do
    begin i  $\leftarrow$  obj_annot_ptr(info(k)); pdf_begin_dict(info(k), 1); pdf_print_ln("/Type_□/Annot");
    if pdf_action_type(pdf_link_action(i))  $\neq$  pdf_action_user then pdf_print_ln("/Subtype_□/Link");
    if pdf_link_attr(i)  $\neq$  null then pdf_print_toks_ln(pdf_link_attr(i));
    pdf_rectangle(pdf_left(i), pdf_top(i), pdf_right(i), pdf_bottom(i));
    if pdf_action_type(pdf_link_action(i))  $\neq$  pdf_action_user then pdf_print("/A_□");
    write_action(pdf_link_action(i)); pdf_end_dict; k  $\leftarrow$  link(k);
    end;
   $\langle$  Flush pdf_start_link_node's created by append_link 783  $\rangle$ ;
  end
```

This code is used in section 780.

783. \langle Flush pdf_start_link_node's created by append_link 783 $\rangle \equiv$

```
k  $\leftarrow$  pdf_link_list;
while k  $\neq$  null do
  begin i  $\leftarrow$  obj_annot_ptr(info(k)); { nodes with info = max_halfword were created by append_link
    and must be flushed here, as they are not linked in any list }
  if info(i) = max_halfword then flush_whatsit_node(i, pdf_start_link_node);
  k  $\leftarrow$  link(k);
  end
```

This code is used in section 782.

784. \langle Write out PDF mark destinations 784 $\rangle \equiv$

```

if pdf_dest_list  $\neq$  null then
  begin  $k \leftarrow$  pdf_dest_list;
  while  $k \neq$  null do
    begin if is_obj_written(info( $k$ )) then
      pdf_error("ext5", "destination_has_been_already_written_(this_shouldn't_happen)");
    else begin  $i \leftarrow$  obj_dest_ptr(info( $k$ ));
      if pdf_dest_named_id( $i$ )  $>$  0 then
        begin pdf_begin_dict(info( $k$ ), 1); pdf_print("/D_");
        end
      else pdf_begin_obj(info( $k$ ), 1);
      pdf_out("["); pdf_print_int(pdf_last_page); pdf_print("_0_R_");
      case pdf_dest_type( $i$ ) of
        pdf_dest_xyz: begin pdf_print("/XYZ_"); pdf_print_mag_bp(pdf_x(pdf_left( $i$ ))); pdf_out("_");
          pdf_print_mag_bp(pdf_y(pdf_top( $i$ ))); pdf_out("_");
          if pdf_dest_xyz_zoom( $i$ ) = null then pdf_print("null")
          else begin pdf_print_int(pdf_dest_xyz_zoom( $i$ ) div 1000); pdf_out(".");
            pdf_print_int((pdf_dest_xyz_zoom( $i$ ) mod 1000));
            end;
          end;
        pdf_dest_fit: pdf_print("/Fit");
        pdf_dest_fith: begin pdf_print("/FitH_"); pdf_print_mag_bp(pdf_y(pdf_top( $i$ )));
          end;
        pdf_dest_fitv: begin pdf_print("/FitV_"); pdf_print_mag_bp(pdf_x(pdf_left( $i$ )));
          end;
        pdf_dest_fitb: pdf_print("/FitB");
        pdf_dest_fitbh: begin pdf_print("/FitBH_"); pdf_print_mag_bp(pdf_y(pdf_top( $i$ )));
          end;
        pdf_dest_fitbv: begin pdf_print("/FitBV_"); pdf_print_mag_bp(pdf_x(pdf_left( $i$ )));
          end;
        pdf_dest_fitr: begin pdf_print("/FitR_"); pdf_print_rect_spec( $i$ );
          end;
        othercases pdf_error("ext5", "unknown_dest_type");
      endcases; pdf_print_ln("]");
      if pdf_dest_named_id( $i$ )  $>$  0 then pdf_end_dict
      else pdf_end_obj;
      end;
       $k \leftarrow$  link( $k$ );
    end;
  end

```

This code is used in section 780.

785. \langle Declare procedures needed in pdf_hlist_out, pdf_vlist_out 727 $\rangle + \equiv$

```

procedure pdf_print_rect_spec( $r$  : pointer); { prints a rect spec }
  begin pdf_print_mag_bp(pdf_x(pdf_left( $r$ ))); pdf_out("_"); pdf_print_mag_bp(pdf_y(pdf_bottom( $r$ )));
  pdf_out("_"); pdf_print_mag_bp(pdf_x(pdf_right( $r$ ))); pdf_out("_"); pdf_print_mag_bp(pdf_y(pdf_top( $r$ )));
  end;

```

786. \langle Write out PDF bead rectangle specifications 786 $\rangle \equiv$

```

if pdf_bead_list  $\neq$  null then
  begin k  $\leftarrow$  pdf_bead_list;
  while k  $\neq$  null do
    begin pdf_new_obj(obj_type_others, 0, 1); pdf_out("["); i  $\leftarrow$  obj_bead_data(info(k));
      { pointer to a whatsit or whatsit-like node }
    pdf_print_rect_spec(i);
    if info(i) = max_halfword then { not a whatsit node, so must be destroyed here }
      flush_whatsit_node(i, pdf_start_thread_node);
    pdf_print_ln("]"); obj_bead_rect(info(k))  $\leftarrow$  obj_ptr; { rewrite obj_bead_data }
    pdf_end_obj; k  $\leftarrow$  link(k);
  end;
end

```

This code is used in section 780.

787. In the end we must flush PDF objects that cannot be written out immediately after shipping out pages.

788. \langle Output outlines 788 $\rangle \equiv$

```

if pdf_first_outline  $\neq$  0 then
  begin pdf_new_dict(obj_type_others, 0, 1); outlines  $\leftarrow$  obj_ptr; l  $\leftarrow$  pdf_first_outline; k  $\leftarrow$  0;
  repeat incr(k); a  $\leftarrow$  open_subentries(l);
    if obj_outline_count(l) > 0 then k  $\leftarrow$  k + a;
    obj_outline_parent(l)  $\leftarrow$  obj_ptr; l  $\leftarrow$  obj_outline_next(l);
  until l = 0;
  pdf_print_ln("/Type_/Outlines"); pdf_indirect_ln("First", pdf_first_outline);
  pdf_indirect_ln("Last", pdf_last_outline); pdf_int_entry_ln("Count", k); pdf_end_dict;
   $\langle$  Output PDF outline entries 789  $\rangle$ ;
  end
else outlines  $\leftarrow$  0

```

This code is used in section 794.

789. \langle Output PDF outline entries 789 $\rangle \equiv$

```

k ← head_tab[obj_type_outline];
while k ≠ 0 do
  begin if obj_outline_parent(k) = pdf_parent_outline then
    begin if obj_outline_prev(k) = 0 then pdf_first_outline ← k;
      if obj_outline_next(k) = 0 then pdf_last_outline ← k;
    end;
    pdf_begin_dict(k, 1); pdf_indirect_ln("Title", obj_outline_title(k));
    pdf_indirect_ln("A", obj_outline_action_objnum(k));
    if obj_outline_parent(k) ≠ 0 then pdf_indirect_ln("Parent", obj_outline_parent(k));
    if obj_outline_prev(k) ≠ 0 then pdf_indirect_ln("Prev", obj_outline_prev(k));
    if obj_outline_next(k) ≠ 0 then pdf_indirect_ln("Next", obj_outline_next(k));
    if obj_outline_first(k) ≠ 0 then pdf_indirect_ln("First", obj_outline_first(k));
    if obj_outline_last(k) ≠ 0 then pdf_indirect_ln("Last", obj_outline_last(k));
    if obj_outline_count(k) ≠ 0 then pdf_int_entry_ln("Count", obj_outline_count(k));
    if obj_outline_attr(k) ≠ 0 then
      begin pdf_print_toks_ln(obj_outline_attr(k)); delete_toks(obj_outline_attr(k));
    end;
    pdf_end_dict; k ← obj_link(k);
  end
end

```

This code is used in section 788.

790. \langle Output article threads 790 $\rangle \equiv$

```

if head_tab[obj_type_thread] ≠ 0 then
  begin pdf_new_obj(obj_type_others, 0, 1); threads ← obj_ptr; pdf_out("[");
  k ← head_tab[obj_type_thread];
  while k ≠ 0 do
    begin pdf_print_int(k); pdf_print("O_R"); k ← obj_link(k);
  end;
  remove_last_space; pdf_print_ln("]"); pdf_end_obj; k ← head_tab[obj_type_thread];
  while k ≠ 0 do
    begin out_thread(k); k ← obj_link(k);
  end;
  end
else threads ← 0

```

This code is used in section 794.

791. Now we are ready to declare our new procedure *ship_out*. It will call *pdf_ship_out* if the integer parameter *pdf_output* is positive; otherwise it will call *dvi_ship_out*, which is the T_EX original *ship_out*.

```

procedure ship_out(p : pointer); { output the box p }
  begin fix_pdfoutput;
  if pdf_output > 0 then pdf_ship_out(p, true)
  else dvi_ship_out(p);
end;

```

792. \langle Initialize variables for PDF output 792 $\rangle \equiv$

```

check_pdfversion; prepare_mag; fixed_decimal_digits  $\leftarrow$  fix_int(pdf_decimal_digits, 0, 4);
min_bp_val  $\leftarrow$  divide_scaled(one_hundred_bp, ten_pow[fixed_decimal_digits + 2], 0);
if pdf_pk_resolution = 0 then { if not set from format file or by user }
  pdf_pk_resolution  $\leftarrow$  pk_dpi; { take it from texmf.cnf }
fixed_pk_resolution  $\leftarrow$  fix_int(pdf_pk_resolution, 72, 8000);
pk_scale_factor  $\leftarrow$  divide_scaled(72, fixed_pk_resolution, 5 + fixed_decimal_digits);
if pdf_pk_mode  $\neq$  null then
  begin kpse_init_prog(`PDFTEX`, fixed_pk_resolution, make_cstring(tokens_to_string(pdf_pk_mode)), nil);
  flush_string;
  end
else kpse_init_prog(`PDFTEX`, fixed_pk_resolution, nil, nil);
kpse_set_program_enabled(kpse_pk_format, 1, kpse_src_compile); set_job_id(year, month, day, time);
if (pdf_unique_resname > 0)  $\wedge$  (pdf_resname_prefix = 0) then pdf_resname_prefix  $\leftarrow$  get_resname_prefix

```

This code is used in section 750.

793. Finishing the PDF output file.

The following procedures sort the table of destination names.

```

define  get_next_char(#)  $\equiv$  c@&#  $\leftarrow$  str_pool[j@&#]; incr(j@&#);
  if (c@&# = 92)  $\wedge$  (j@&# < e@&#) then
    begin c@&#  $\leftarrow$  str_pool[j@&#]; incr(j@&#);
    if (c@&#  $\geq$  48)  $\wedge$  (c@&#  $\leq$  55) then
      begin c@&#  $\leftarrow$  c@&# - 48;
      if (j@&# < e@&#)  $\wedge$  (str_pool[j@&#]  $\geq$  48)  $\wedge$  (str_pool[j@&#]  $\leq$  55) then
        begin c@&#  $\leftarrow$  8 * c@&# + str_pool[j@&#] - 48; incr(j@&#);
        if (j@&# < e@&#)  $\wedge$  (str_pool[j@&#]  $\geq$  48)  $\wedge$  (str_pool[j@&#]  $\leq$  55)  $\wedge$  (c@&# < 32) then
          begin c@&#  $\leftarrow$  8 * c@&# + str_pool[j@&#] - 48; incr(j@&#);
          end;
        end;
      end;
    end
  else begin case c@&# of
    98: c@&#  $\leftarrow$  8; { ‘b’: backspace }
    102: c@&#  $\leftarrow$  12; { ‘f’: form feed }
    110: c@&#  $\leftarrow$  10; { ‘n’: line feed }
    114: c@&#  $\leftarrow$  13; { ‘r’: carriage return }
    116: c@&#  $\leftarrow$  9; { ‘t’: horizontal tab }
    { nothing to do for ‘\’, ‘(’, ‘)’ }
    othercases do_nothing
    endcases;
  end;
end

function str_less_str(s1, s2 : str_number): boolean; { compare two pdf strings }
  var j1, j2, e1, e2: pool_pointer; c1, c2: packed_ASCII_code;
  begin { Minimal requirement: output of \pdfescapestring must be supported. }
    { This implementation also supports all escape sequences }
    { listed in the table ‘Escape sequences in literal strings’ }
    { of the pdf specification. }
    { End-of-line markers are not detected: }
    { The marker is not replaced by ‘\n’ or removed if it is escaped. }
  j1  $\leftarrow$  str_start[s1]; j2  $\leftarrow$  str_start[s2]; e1  $\leftarrow$  j1 + length(s1); e2  $\leftarrow$  j2 + length(s2);
  while (j1 < e1)  $\wedge$  (j2 < e2) do
    begin { get next character of first string }
      get_next_char(1); { get next character of second string }
      get_next_char(2); { compare characters }
    if c1 < c2 then
      begin str_less_str  $\leftarrow$  true; return;
    end
    else if c1 > c2 then
      begin str_less_str  $\leftarrow$  false; return;
    end;
    end; { compare string lengths }
  if (j1  $\geq$  e1)  $\wedge$  (j2 < e2) then str_less_str  $\leftarrow$  true
  else str_less_str  $\leftarrow$  false;
exit: end;

procedure sort_dest_names(l, r : integer); { sorts dest_names by names }
  var i, j: integer; s: str_number; e: dest_name_entry;
  begin i  $\leftarrow$  l; j  $\leftarrow$  r; s  $\leftarrow$  dest_names[(l + r)  $\div$  2].objname;
  repeat while str_less_str(dest_names[i].objname, s) do incr(i);

```



```

while str_less_str(s, dest_names[j].objname) do decr(j);
if i ≤ j then
  begin e ← dest_names[i]; dest_names[i] ← dest_names[j]; dest_names[j] ← e; incr(i); decr(j);
  end;
until i > j;
if l < j then sort_dest_names(l, j);
if i < r then sort_dest_names(i, r);
end;

```

794. Now the finish of PDF output file. At this moment all Page objects are already written completely to PDF output file.

⟨Finish the PDF file 794⟩ ≡

```

if total_pages = 0 then
  begin print_nl("No_pages_of_output.");
  if pdf_gone > 0 then garbage_warning;
  end
else begin if fixed_pdf_draftmode = 0 then
  begin pdf_flush; { to make sure that the output file name has been already created }
  if total_pages mod pages_tree_kids_max ≠ 0 then
    obj.info(pdf_last_pages) ← total_pages mod pages_tree_kids_max;
    { last pages object may have less than pages_tree_kids_max children }
  flush_jbig2_page0_objects; { flush page 0 objects from JBIG2 images, if any }
  ⟨Check for non-existing pages 797⟩;
  ⟨Reverse the linked list of Page and Pages objects 798⟩;
  ⟨Check for non-existing destinations 796⟩;
  ⟨Output fonts definition 799⟩;
  ⟨Output pages tree 800⟩;
  ⟨Output outlines 788⟩;
  ⟨Output name tree 802⟩;
  ⟨Output article threads 790⟩;
  ⟨Output the catalog object 804⟩;
  pdf_print_info; { last candidate for object stream }
  if pdf_os_enable then
    begin pdf_os_switch(true); pdf_os_write_objstream; pdf_flush; pdf_os_switch(false);
    ⟨Output the cross-reference stream dictionary 812⟩;
    pdf_flush;
    end
  else begin ⟨Output the obj_tab 811⟩;
    end;
  ⟨Output the trailer 813⟩;
  pdf_flush; print_nl("Output_written_on_"); print_file_name(0, output_file_name, 0); print("_");
  print_int(total_pages); print("_page");
  if total_pages ≠ 1 then print_char("s");
  print(",_"); print_int(pdf_offset); print("_bytes).");
  end;
  libpdffinish;
  if fixed_pdf_draftmode = 0 then b_close(pdf_file)
  else pdf_warning(0, "\pdfdraftmode_enabled,_not_changing_output_pdf", true, true)
  end

```

This code is used in section 1511.

795. Destinations that have been referenced but don't exist have $obj_dest_ptr = null$. Leaving them undefined might cause troubles for PDF browsers, so we need to fix them.

```

procedure pdf_fix_dest( $k : integer$ );
  begin if  $obj\_dest\_ptr(k) \neq null$  then return;
  pdf_warning("dest", "", false, false);
  if  $obj\_info(k) < 0$  then
    begin print("name{"); print( $-obj\_info(k)$ ); print("}");
    end
  else begin print("num"); print_int( $obj\_info(k)$ );
  end;
  print(" has been referenced but does not exist, replaced by a fixed one"); print_ln;
  print_ln; pdf_begin_obj( $k, 1$ ); pdf_out("["); pdf_print_int(head_tab[obj_type_page]);
  pdf_print_ln("O_R/Fit"); pdf_end_obj;
end;

```

796. \langle Check for non-existing destinations 796 $\rangle \equiv$

```

 $k \leftarrow head\_tab[obj\_type\_dest]$ ;
while  $k \neq 0$  do
  begin pdf_fix_dest( $k$ );  $k \leftarrow obj\_link(k)$ ;
  end

```

This code is used in section 794.

797. \langle Check for non-existing pages 797 $\rangle \equiv$

```

 $k \leftarrow head\_tab[obj\_type\_page]$ ;
while  $obj\_aux(k) = 0$  do
  begin pdf_warning("dest", "Page_", false, false); print_int( $obj\_info(k)$ );
  print(" has been referenced but does not exist!"); print_ln; print_ln;  $k \leftarrow obj\_link(k)$ ;
  end;
   $head\_tab[obj\_type\_page] \leftarrow k$ 

```

This code is used in section 794.

798. \langle Reverse the linked list of Page and Pages objects 798 $\rangle \equiv$

```

 $k \leftarrow head\_tab[obj\_type\_page]$ ;  $l \leftarrow 0$ ;
repeat  $i \leftarrow obj\_link(k)$ ;  $obj\_link(k) \leftarrow l$ ;  $l \leftarrow k$ ;  $k \leftarrow i$ ;
until  $k = 0$ ;
 $head\_tab[obj\_type\_page] \leftarrow l$ ;  $k \leftarrow head\_tab[obj\_type\_pages]$ ;  $pages\_tail \leftarrow k$ ;  $l \leftarrow 0$ ;
repeat  $i \leftarrow obj\_link(k)$ ;  $obj\_link(k) \leftarrow l$ ;  $l \leftarrow k$ ;  $k \leftarrow i$ ;
until  $k = 0$ ;
 $head\_tab[obj\_type\_pages] \leftarrow l$ 

```

This code is used in section 794.

799. $\langle \text{Output fonts definition 799} \rangle \equiv$

```

for  $k \leftarrow \text{font\_base} + 1$  to  $\text{font\_ptr}$  do
  if  $\text{font\_used}[k] \wedge \text{hasfmentry}(k) \wedge (\text{pdf\_font\_num}[k] < 0)$  then
    begin  $i \leftarrow -\text{pdf\_font\_num}[k]$ ;  $\text{pdfassert}(\text{pdf\_font\_num}[i] > 0)$ ;
    for  $j \leftarrow 0$  to 255 do
      if  $\text{pdf\_char\_marked}(k, j)$  then  $\text{pdf\_mark\_char}(i, j)$ ;
    if  $(\text{length}(\text{pdf\_font\_attr}[i]) = 0) \wedge (\text{length}(\text{pdf\_font\_attr}[k]) \neq 0)$  then
       $\text{pdf\_font\_attr}[i] \leftarrow \text{pdf\_font\_attr}[k]$ 
    else if  $(\text{length}(\text{pdf\_font\_attr}[k]) = 0) \wedge (\text{length}(\text{pdf\_font\_attr}[i]) \neq 0)$  then
       $\text{pdf\_font\_attr}[k] \leftarrow \text{pdf\_font\_attr}[i]$ 
    else if  $(\text{length}(\text{pdf\_font\_attr}[i]) \neq 0) \wedge (\text{length}(\text{pdf\_font\_attr}[k]) \neq 0) \wedge \neg \text{str\_eq\_str}(\text{pdf\_font\_attr}[i],$ 
       $\text{pdf\_font\_attr}[k])$  then
      begin  $\text{pdf\_warning}("\backslash\text{pdf}fontattr", "fonts\_", false, false)$ ;  $\text{print\_font\_identifier}(i)$ ;
       $\text{print}("\_and\_")$ ;  $\text{print\_font\_identifier}(k)$ ;
       $\text{print}("\_have\_conflicting\_attributes;\_I\_will\_ignore\_the\_attributes\_assigned\_to\_")$ ;
       $\text{print\_font\_identifier}(i)$ ;  $\text{print\_ln}$ ;  $\text{print\_ln}$ ;
      end;
    end;
   $\text{fixed\_gen\_tounicode} \leftarrow \text{pdf\_gen\_tounicode}$ ;  $k \leftarrow \text{head\_tab}[\text{obj\_type\_font}]$ ;
while  $k \neq 0$  do
  begin  $f \leftarrow \text{obj\_info}(k)$ ;  $\text{pdfassert}(\text{pdf\_font\_num}[f] > 0)$ ;  $\text{do\_pdf\_font}(k, f)$ ;  $k \leftarrow \text{obj\_link}(k)$ ;
  end;
 $\text{write\_fontstuff}$ 

```

This code is used in section 794.

800. We will generate in each single step the parents of all Pages/Page objects in the previous level. These new generated Pages object will create a new level of the Pages tree. We will repeat this until we have only one Pages object. This one will be the Root object.

```

<Output pages tree 800> ≡
  a ← sys_obj_ptr + 1;
    { all Pages objects whose children are not Page objects should have index greater than a }
  l ← head_tab[obj_type_pages]; { l is the index of current Pages object which is being output }
  k ← head_tab[obj_type_page]; { k is the index of current child of l }
  b ← 0;
  repeat i ← 0; { counter of Pages object in current level }
    c ← 0; { first Pages object in previous level }
    if obj_link(l) = 0 then is_root ← true
      { only Pages object; total pages is not greater than pages_tree_kids_max }
    else is_root ← false;
    repeat if ¬is_root then
      begin if i mod pages_tree_kids_max = 0 then
        begin { create a new Pages object for next level }
          pdf_last_pages ← pdf_new_objnum;
          if c = 0 then c ← pdf_last_pages;
          obj_link(pages_tail) ← pdf_last_pages; pages_tail ← pdf_last_pages; obj_link(pdf_last_pages) ← 0;
          obj_info(pdf_last_pages) ← obj_info(l);
          end
        else obj_info(pdf_last_pages) ← obj_info(pdf_last_pages) + obj_info(l);
          end;
      <Output the current Pages object in this level 801>;
      incr(i); l ← obj_link(l);
    until (l = c);
    b ← c;
    if l = 0 then goto done;
  until false;
done:

```

This code is used in section 794.

```

801. <Output the current Pages object in this level 801> ≡
  pdf_begin_dict(l, 1); pdf_print_ln("/Type□/Pages"); pdf_int_entry_ln("Count", obj_info(l));
  if ¬is_root then pdf_indirect_ln("Parent", pdf_last_pages);
  pdf_print("/Kids□[""); j ← 0;
  repeat pdf_print_int(k); pdf_print("□0□R□"); k ← obj_link(k); incr(j);
  until ((l < a) ∧ (j = obj_info(l))) ∨ (k = 0) ∨ ((k = b) ∧ (b ≠ 0)) ∨ (j = pages_tree_kids_max);
  remove_last_space; pdf_print_ln(""]");
  if k = 0 then
    begin k ← head_tab[obj_type_pages]; head_tab[obj_type_pages] ← 0;
    end;
  if is_root ∧ (pdf_pages_attr ≠ null) then pdf_print_toks_ln(pdf_pages_attr);
  pdf_end_dict;

```

This code is used in section 800.

802. The name tree is very similar to Pages tree so its construction should be certain from Pages tree construction. For intermediate node *obj_info* will be the first name and *obj_link* will be the last name in `\Limits` array. Note that *pdf_dest_names_ptr* will be less than *obj_ptr*, so we test if *k* < *pdf_dest_names_ptr* then *k* is index of leaf in *dest_names*; else *k* will be index in *obj_tab* of some intermediate node.

```

<Output name tree 802> ≡
  if pdf_dest_names_ptr = 0 then
    begin dests ← 0; goto done1;
  end;
  sort_dest_names(0, pdf_dest_names_ptr - 1); names_head ← 0; names_tail ← 0; k ← 0;
  { index of current child of l; if k < pdf_dest_names_ptr then this is pointer to dest_names array;
    otherwise it is the pointer to obj_tab (object number) }
  is_names ← true; { flag whether Names or Kids }
  b ← 0;
  repeat repeat pdf_create_obj(obj_type_others, 0); { create a new node }
    l ← obj_ptr;
    if b = 0 then b ← l; { first in this level }
    if names_head = 0 then
      begin names_head ← l; names_tail ← l;
      end
    else begin obj_link(names_tail) ← l; names_tail ← l;
    end;
    obj_link(names_tail) ← 0; <Output the current node in this level 803>;
  until b = 0;
  if k = l then
    begin dests ← l; goto done1;
    end;
  until false;
done1: if (dests ≠ 0) ∨ (pdf_names_toks ≠ null) then
  begin pdf_new_dict(obj_type_others, 0, 1);
  if (dests ≠ 0) then pdf_indirect_ln("Dests", dests);
  if pdf_names_toks ≠ null then
    begin pdf_print_toks_ln(pdf_names_toks); delete_toks(pdf_names_toks);
    end;
  pdf_end_dict; names_tree ← obj_ptr;
  end
  else names_tree ← 0

```

This code is used in section 794.

803. \langle Output the current node in this level [803](#) $\rangle \equiv$

```
pdf_begin_dict(l, 1); j ← 0;
if is_names then
  begin obj_info(l) ← dest_names[k].objname; pdf_print("/Names_");
  repeat pdf_print_str(dest_names[k].objname); pdf_out("_"); pdf_print_int(dest_names[k].objnum);
    pdf_print("_O_R_"); incr(j); incr(k);
  until (j = name_tree.kids_max) ∨ (k = pdf_dest_names_ptr);
  remove_last_space; pdf_print_ln("]"); obj_aux(l) ← dest_names[k - 1].objname;
  if k = pdf_dest_names_ptr then
    begin is_names ← false; k ← names_head; b ← 0;
    end;
  end
else begin obj_info(l) ← obj_info(k); pdf_print("/Kids_");
  repeat pdf_print_int(k); pdf_print("_O_R_"); incr(j); obj_aux(l) ← obj_aux(k); k ← obj_link(k);
  until (j = name_tree.kids_max) ∨ (k = b) ∨ (obj_link(k) = 0);
  remove_last_space; pdf_print_ln("]");
  if k = b then b ← 0;
  end;
pdf_print("/Limits_"); pdf_print_str(obj_info(l)); pdf_out("_"); pdf_print_str(obj_aux(l));
pdf_print_ln("]"); pdf_end_dict;
```

This code is used in section [802](#).

804. \langle Output the catalog object [804](#) $\rangle \equiv$

```
pdf_new_dict(obj_type_others, 0, 1); root ← obj_ptr; pdf_print_ln("/Type_/Catalog");
pdf_indirect_ln("Pages", pdf_last_pages);
if threads ≠ 0 then pdf_indirect_ln("Threads", threads);
if outlines ≠ 0 then pdf_indirect_ln("Outlines", outlines);
if names_tree ≠ 0 then pdf_indirect_ln("Names", names_tree);
if pdf_catalog_toks ≠ null then
  begin pdf_print_toks_ln(pdf_catalog_toks); delete_toks(pdf_catalog_toks);
  end;
if pdf_catalog_openaction ≠ 0 then pdf_indirect_ln("OpenAction", pdf_catalog_openaction);
pdf_end_dict
```

This code is used in section [794](#).

805. If the same keys in a dictionary are given several times, then it is not defined which value is chosen by an application. Therefore the keys */Producer* and */Creator* are only set if the token list *pdf_info_toks* converted to a string does not contain these key strings.

```

procedure pdf_print_info; { print info object }
  var s: str_number;
      creator_given, producer_given, creationdate_given, moddate_given, trapped_given: boolean;
begin pdf_new_dict(obj_type_others, 0, 3); { keep Info readable unless explicitly forced }
  creator_given ← false; producer_given ← false; creationdate_given ← false; moddate_given ← false;
  trapped_given ← false;
  if pdf_info_toks ≠ null then
    begin s ← tokens_to_string(pdf_info_toks); creator_given ← substr_of_str("/Creator", s);
    producer_given ← substr_of_str("/Producer", s);
    creationdate_given ← substr_of_str("/CreationDate", s);
    moddate_given ← substr_of_str("/ModDate", s); trapped_given ← substr_of_str("/Trapped", s);
    end;
  if ¬producer_given then
    begin ⟨Print the Producer key 806⟩;
    end;
  if pdf_info_toks ≠ null then
    begin if length(s) > 0 then
      begin pdf_print_ln(s);
      end;
    flush_str(s); delete_toks(pdf_info_toks);
    end;
  if ¬creator_given then pdf_str_entry_ln("Creator", "TeX");
  if pdf_info_omit_date = 0 then
    begin if ¬creationdate_given then
      begin ⟨Print the CreationDate key 807⟩;
      end;
    if ¬moddate_given then
      begin ⟨Print the ModDate key 808⟩;
      end;
    end;
  if ¬trapped_given then
    begin pdf_print_ln("/Trapped_□/False");
    end;
  if pdf_suppress_ptex_info mod 2 = 0 then
    begin pdf_str_entry_ln("PTEX.Fullbanner", pdf_tex_banner);
    end;
  pdf_end_dict;
end;

```

806. ⟨Print the Producer key 806⟩ ≡

```

pdf_print("/Producer_□(pdfTeX-"); pdf_print_int(pdf_tex_version div 100); pdf_out(".");
pdf_print_int(pdf_tex_version mod 100); pdf_out("."); pdf_print(pdf_tex_revision); pdf_print_ln(")")

```

This code is used in section 805.

807. ⟨Print the CreationDate key 807⟩ ≡

```

print_creation_date;

```

This code is used in section 805.

808. \langle Print the ModDate key 808 $\rangle \equiv$
print_mod_date;

This code is used in section 805.

809. \langle Global variables 13 $\rangle + \equiv$
pdfTeX_banner: str_number; { the complete banner }

810. \langle Build a linked list of free objects 810 $\rangle \equiv$
l \leftarrow 0; *set_obj_fresh*(*l*); { null object at begin of list of free objects }
for *k* \leftarrow 1 **to** *sys_obj_ptr* **do**
 if \neg *is_obj_written*(*k*) **then**
 begin *obj_link*(*l*) \leftarrow *k*; *l* \leftarrow *k*;
 end;
obj_link(*l*) \leftarrow 0

This code is used in sections 811 and 812.

811. \langle Output the *obj_tab* 811 $\rangle \equiv$
 \langle Build a linked list of free objects 810 \rangle ;
pdf_save_offset \leftarrow *pdf_offset*; *pdf_print_ln*("xref"); *pdf_print*("0_"); *pdf_print_int_ln*(*obj_ptr* + 1);
pdf_print_fw_int(*obj_link*(0), 10); *pdf_print_ln*("_65535_f_");
for *k* \leftarrow 1 **to** *obj_ptr* **do**
 begin if \neg *is_obj_written*(*k*) **then**
 begin *pdf_print_fw_int*(*obj_link*(*k*), 10); *pdf_print_ln*("_00000_f_");
 end
 else begin *pdf_print_fw_int*(*obj_offset*(*k*), 10); *pdf_print_ln*("_00000_n_");
 end;
end

This code is used in section 794.

812. \langle Output the cross-reference stream dictionary [812](#) $\rangle \equiv$

```
pdf_new_dict(obj_type_others, 0, 0);
if ((obj_offset(sys_obj_ptr)/256) > 16777215) then xref_offset_width ← 5
else if obj_offset(sys_obj_ptr) > 16777215 then xref_offset_width ← 4
    else if obj_offset(sys_obj_ptr) > 65535 then xref_offset_width ← 3
        else xref_offset_width ← 2;
 $\langle$  Build a linked list of free objects 810  $\rangle$ ;
pdf_print_ln("/Type_XRef"); pdf_print("/Index_0_"); pdf_print_int(obj_ptr + 1); pdf_print_ln("]");
pdf_int_entry_ln("Size", obj_ptr + 1); pdf_print("/W_1_"); pdf_print_int(xref_offset_width);
pdf_print_ln("_1_"); pdf_indirect_ln("Root", root); pdf_indirect_ln("Info", obj_ptr - 1);
if pdf_trailer_toks ≠ null then
    begin pdf_print_toks_ln(pdf_trailer_toks); delete_toks(pdf_trailer_toks);
    end;
if pdf_trailer_id_toks ≠ null then print_ID_alt(pdf_trailer_id_toks)
else print_ID(output_file_name);
pdf_print_nl; pdf_begin_stream;
for k ← 0 to sys_obj_ptr do
    begin if ¬is_obj_written(k) then
        begin { a free object }
            pdf_out(0); pdf_out_bytes(obj_link(k), xref_offset_width); pdf_out(255);
            end
        else begin if obj_os_idx(k) = -1 then
            begin { object not in object stream }
                pdf_out(1); pdf_out_bytes(obj_offset(k), xref_offset_width); pdf_out(0);
                end
            else begin { object in object stream }
                pdf_out(2); pdf_out_bytes(obj_offset(k), xref_offset_width); pdf_out(obj_os_idx(k));
                end;
            end;
        end;
    end;
pdf_end_stream;
```

This code is used in section [794](#).

813. \langle Output the trailer [813](#) $\rangle \equiv$

```
if ¬pdf_os_enable then
    begin pdf_print_ln("trailer"); pdf_print("<<_"); pdf_int_entry_ln("Size", sys_obj_ptr + 1);
        pdf_indirect_ln("Root", root); pdf_indirect_ln("Info", sys_obj_ptr);
        if pdf_trailer_toks ≠ null then
            begin pdf_print_toks_ln(pdf_trailer_toks); delete_toks(pdf_trailer_toks);
            end;
        if pdf_trailer_id_toks ≠ null then print_ID_alt(pdf_trailer_id_toks)
        else print_ID(output_file_name);
        pdf_print_ln("_>>");
        end;
pdf_print_ln("startxref");
if pdf_os_enable then pdf_print_int_ln(obj_offset(sys_obj_ptr))
else pdf_print_int_ln(pdf_save_offset);
pdf_print_ln("%EOF")
```

This code is used in section [794](#).

814. Packaging. We're essentially done with the parts of T_EX that are concerned with the input (*get_next*) and the output (*ship_out*). So it's time to get heavily into the remaining part, which does the real work of typesetting.

After lists are constructed, T_EX wraps them up and puts them into boxes. Two major subroutines are given the responsibility for this task: *hpack* applies to horizontal lists (hlists) and *vpack* applies to vertical lists (vlists). The main duty of *hpack* and *vpack* is to compute the dimensions of the resulting boxes, and to adjust the glue if one of those dimensions is pre-specified. The computed sizes normally enclose all of the material inside the new box; but some items may stick out if negative glue is used, if the box is overfull, or if a \vbox includes other boxes that have been shifted left.

The subroutine call *hpack*(*p*, *w*, *m*) returns a pointer to an *hlist_node* for a box containing the hlist that starts at *p*. Parameter *w* specifies a width; and parameter *m* is either 'exactly' or 'additional'. Thus, *hpack*(*p*, *w*, *exactly*) produces a box whose width is exactly *w*, while *hpack*(*p*, *w*, *additional*) yields a box whose width is the natural width plus *w*. It is convenient to define a macro called 'natural' to cover the most common case, so that we can say *hpack*(*p*, *natural*) to get a box that has the natural width of list *p*.

Similarly, *vpack*(*p*, *w*, *m*) returns a pointer to a *vlist_node* for a box containing the vlist that starts at *p*. In this case *w* represents a height instead of a width; the parameter *m* is interpreted as in *hpack*.

```
define exactly = 0 { a box dimension is pre-specified }
define additional = 1 { a box dimension is increased from the natural one }
define natural ≡ 0, additional { shorthand for parameters to hpack and vpack }
```

815. The parameters to *hpack* and *vpack* correspond to T_EX's primitives like '\hbox to 300pt', '\hbox spread 10pt'; note that '\hbox' with no dimension following it is equivalent to '\hbox spread 0pt'. The *scan_spec* subroutine scans such constructions in the user's input, including the mandatory left brace that follows them, and it puts the specification onto *save_stack* so that the desired box can later be obtained by executing the following code:

```
save_ptr ← save_ptr - 2;
hpack(p, saved(1), saved(0)).
```

Special care is necessary to ensure that the special *save_stack* codes are placed just below the new group code, because scanning can change *save_stack* when \csname appears.

```
procedure scan_spec(c : group_code; three_codes : boolean); { scans a box specification and left brace }
  label found;
  var s : integer; { temporarily saved value }
  spec_code : exactly .. additional;
  begin if three_codes then s ← saved(0);
  if scan_keyword("to") then spec_code ← exactly
  else if scan_keyword("spread") then spec_code ← additional
  else begin spec_code ← additional; cur_val ← 0; goto found;
  end;
  scan_normal_dimen;
found: if three_codes then
  begin saved(0) ← s; incr(save_ptr);
  end;
  saved(0) ← spec_code; saved(1) ← cur_val; save_ptr ← save_ptr + 2; new_save_level(c); scan_left_brace;
end;
```

816. To figure out the glue setting, *hpack* and *vpack* determine how much stretchability and shrinkability are present, considering all four orders of infinity. The highest order of infinity that has a nonzero coefficient is then used as if no other orders were present.

For example, suppose that the given list contains six glue nodes with the respective stretchabilities 3pt, 8fil, 5fil, 6pt, −3fil, −8fil. Then the total is essentially 2fil; and if a total additional space of 6pt is to be achieved by stretching, the actual amounts of stretch will be 0pt, 0pt, 15pt, 0pt, −9pt, and 0pt, since only ‘fil’ glue will be considered. (The ‘fil’ glue is therefore not really stretching infinitely with respect to ‘fil’; nobody would actually want that to happen.)

The arrays *total_stretch* and *total_shrink* are used to determine how much glue of each kind is present. A global variable *last_badness* is used to implement `\badness`.

```

⟨Global variables 13⟩ +=
total_stretch, total_shrink: array [glue_ord] of scaled; { glue found by hpack or vpack }
last_badness: integer; { badness of the most recently packaged box }

```

817. If the global variable *adjust_tail* is non-null, the *hpack* routine also removes all occurrences of *ins_node*, *mark_node*, and *adjust_node* items and appends the resulting material onto the list that ends at location *adjust_tail*.

```

⟨Global variables 13⟩ +=
adjust_tail: pointer; { tail of adjustment list }

```

818. ⟨Set initial values of key variables 21⟩ +=
adjust_tail ← *null*; *last_badness* ← 0;

```

819. ⟨Global variables 13⟩ +=
pdf_font_blink: ↑internal_font_number; { link to base font (used for expanded fonts only) }
pdf_font_elinek: ↑internal_font_number; { link to expanded fonts (used for base fonts only) }
pdf_font_stretch: ↑integer; { link to font expanded by stretch limit }
pdf_font_shrink: ↑integer; { link to font expanded by shrink limit }
pdf_font_step: ↑integer; { amount of one step of expansion }
pdf_font_expand_ratio: ↑integer; { expansion ratio of a particular font }
pdf_font_auto_expand: ↑boolean; { this font is auto-expanded? }
pdf_font_lp_base: ↑integer; { base of left-protruding factor }
pdf_font_rp_base: ↑integer; { base of right-protruding factor }
pdf_font_ef_base: ↑integer; { base of font expansion factor }
pdf_font_kn_bs_base: ↑integer; { base of kern before space }
pdf_font_st_bs_base: ↑integer; { base of stretch before space }
pdf_font_sh_bs_base: ↑integer; { base of shrink before space }
pdf_font_kn_bc_base: ↑integer; { base of kern before character }
pdf_font_kn_ac_base: ↑integer; { base of kern after character }
font_expand_ratio: integer; { current expansion ratio }
last_leftmost_char: pointer;
last_rightmost_char: pointer;
hlist_stack: array [0 .. max_hlist_stack] of pointer;
    { stack for find_protchar_left() and find_protchar_right() }
hlist_stack_level: 0 .. max_hlist_stack; { fill level for hlist_stack }

```

```

820. define cal_margin_kern_var(#) ≡
    begin character(cp) ← character(#); font(cp) ← font(#); do_subst_font(cp, 1000);
    if font(cp) ≠ font(#) then
        margin_kern_stretch ← margin_kern_stretch + left_pw(#) − left_pw(cp);
        font(cp) ← font(#); do_subst_font(cp, −1000);
    if font(cp) ≠ font(#) then
        margin_kern_shrink ← margin_kern_shrink + left_pw(cp) − left_pw(#);
    end

```

```

⟨ Calculate variations of marginal kerns 820 ⟩ ≡
    begin lp ← last_leftmost_char; rp ← last_rightmost_char; fast_get_avail(cp);
    if lp ≠ null then cal_margin_kern_var(lp);
    if rp ≠ null then cal_margin_kern_var(rp);
    free_avail(cp);
    end

```

This code is used in section 1025.

821. Here is *hpack*, which is place where we do font substituting when font expansion is being used. We define some constants used when calling *hpack* to deal with font expansion.

```

define cal_expand_ratio  $\equiv$  2 { calculate amount for font expansion after breaking paragraph into lines }
define subst_ex_font  $\equiv$  3 { substitute fonts }
define substituted = 3 { subtype of kern nodes that should be substituted }
define left_pw( $\#$ )  $\equiv$  char_pw( $\#$ , left_side)
define right_pw( $\#$ )  $\equiv$  char_pw( $\#$ , right_side)

function check_expand_pars( $f$  : internal_font_number): boolean;
  var k: internal_font_number;
  begin check_expand_pars  $\leftarrow$  false;
  if (pdf_font_step[f] = 0)  $\vee$  ((pdf_font_stretch[f] = null_font)  $\wedge$  (pdf_font_shrink[f] = null_font)) then
    return;
  if cur_font_step < 0 then cur_font_step  $\leftarrow$  pdf_font_step[f]
  else if cur_font_step  $\neq$  pdf_font_step[f] then pdf_error("font_expansion",
    "using_fonts_with_different_step_of_expansion_in_one_paragraph_is_not_allowed");
  k  $\leftarrow$  pdf_font_stretch[f];
  if k  $\neq$  null_font then
    begin if max_stretch_ratio < 0 then max_stretch_ratio  $\leftarrow$  pdf_font_expand_ratio[k]
    else if max_stretch_ratio  $\neq$  pdf_font_expand_ratio[k] then pdf_error("font_expansion",
      "using_fonts_with_different_limit_of_expansion_in_one_paragraph_is_not_allowed");
    end;
  k  $\leftarrow$  pdf_font_shrink[f];
  if k  $\neq$  null_font then
    begin if max_shrink_ratio < 0 then max_shrink_ratio  $\leftarrow$  -pdf_font_expand_ratio[k]
    else if max_shrink_ratio  $\neq$  -pdf_font_expand_ratio[k] then pdf_error("font_expansion",
      "using_fonts_with_different_limit_of_expansion_in_one_paragraph_is_not_allowed");
    end;
  check_expand_pars  $\leftarrow$  true;
  end;

function char_stretch( $f$  : internal_font_number;  $c$  : eight_bits): scaled;
  var k: internal_font_number; dw: scaled; ef: integer;
  begin char_stretch  $\leftarrow$  0; k  $\leftarrow$  pdf_font_stretch[f]; ef  $\leftarrow$  get_ef_code(f, c);
  if (k  $\neq$  null_font)  $\wedge$  (ef > 0) then
    begin dw  $\leftarrow$  char_width(k)(char_info(k)(c)) - char_width(f)(char_info(f)(c));
    if dw > 0 then char_stretch  $\leftarrow$  round_xn_over_d(dw, ef, 1000);
    end;
  end;

function char_shrink( $f$  : internal_font_number;  $c$  : eight_bits): scaled;
  var k: internal_font_number; dw: scaled; ef: integer;
  begin char_shrink  $\leftarrow$  0; k  $\leftarrow$  pdf_font_shrink[f]; ef  $\leftarrow$  get_ef_code(f, c);
  if (k  $\neq$  null_font)  $\wedge$  (ef > 0) then
    begin dw  $\leftarrow$  char_width(f)(char_info(f)(c)) - char_width(k)(char_info(k)(c));
    if dw > 0 then char_shrink  $\leftarrow$  round_xn_over_d(dw, ef, 1000);
    end;
  end;

function get_kern( $f$  : internal_font_number; lc, rc : eight_bits): scaled;
  label continue;
  var i: four_quarters; j: four_quarters; k: font_index;
  begin get_kern  $\leftarrow$  0; i  $\leftarrow$  char_info(f)(lc);
  if char_tag(i)  $\neq$  lig_tag then return;
  k  $\leftarrow$  lig_kern_start(f)(i); j  $\leftarrow$  font_info[k].qqqq;
  if skip_byte(j)  $\leq$  stop_flag then goto continue + 1;

```

```

     $k \leftarrow \text{lig\_kern\_restart}(f)(j);$ 
  continue:  $j \leftarrow \text{font\_info}[k].\text{qqqq};$ 
  continue + 1: if ( $\text{next\_char}(j) = \text{rc}$ )  $\wedge$  ( $\text{skip\_byte}(j) \leq \text{stop\_flag}$ )  $\wedge$  ( $\text{op\_byte}(j) \geq \text{kern\_flag}$ ) then
    begin  $\text{get\_kern} \leftarrow \text{char\_kern}(f)(j);$  return;
    end;
  if  $\text{skip\_byte}(j) = \text{qi}(0)$  then  $\text{incr}(k)$ 
  else begin if  $\text{skip\_byte}(j) \geq \text{stop\_flag}$  then return;
     $k \leftarrow k + \text{qo}(\text{skip\_byte}(j)) + 1;$ 
    end;
  goto continue;
end;

function  $\text{kern\_stretch}(p : \text{pointer})$ : scaled;
  var  $l, r$ : pointer;  $d$ : scaled;
  begin  $\text{kern\_stretch} \leftarrow 0;$ 
  if ( $\text{prev\_char\_p} = \text{null}$ )  $\vee$  ( $\text{link}(\text{prev\_char\_p}) \neq p$ )  $\vee$  ( $\text{link}(p) = \text{null}$ ) then return;
   $l \leftarrow \text{prev\_char\_p};$   $r \leftarrow \text{link}(p);$ 
  if  $\neg \text{is\_char\_node}(l)$  then
    if  $\text{type}(l) = \text{ligature\_node}$  then  $l \leftarrow \text{lig\_char}(l)$ 
    else return;
  if  $\neg \text{is\_char\_node}(r)$  then
    if  $\text{type}(r) = \text{ligature\_node}$  then  $r \leftarrow \text{lig\_char}(r)$ 
    else return;
  if  $\neg((\text{font}(l) = \text{font}(r)) \wedge (\text{pdf\_font\_stretch}[\text{font}(l)] \neq \text{null\_font}))$  then return;
   $d \leftarrow \text{get\_kern}(\text{pdf\_font\_stretch}[\text{font}(l)], \text{character}(l), \text{character}(r));$ 
   $\text{kern\_stretch} \leftarrow \text{round\_xn\_over\_d}(d - \text{width}(p), \text{get\_ef\_code}(\text{font}(l), \text{character}(l)), 1000);$ 
end;

function  $\text{kern\_shrink}(p : \text{pointer})$ : scaled;
  var  $l, r$ : pointer;  $d$ : scaled;
  begin  $\text{kern\_shrink} \leftarrow 0;$ 
  if ( $\text{prev\_char\_p} = \text{null}$ )  $\vee$  ( $\text{link}(\text{prev\_char\_p}) \neq p$ )  $\vee$  ( $\text{link}(p) = \text{null}$ ) then return;
   $l \leftarrow \text{prev\_char\_p};$   $r \leftarrow \text{link}(p);$ 
  if  $\neg \text{is\_char\_node}(l)$  then
    if  $\text{type}(l) = \text{ligature\_node}$  then  $l \leftarrow \text{lig\_char}(l)$ 
    else return;
  if  $\neg \text{is\_char\_node}(r)$  then
    if  $\text{type}(r) = \text{ligature\_node}$  then  $r \leftarrow \text{lig\_char}(r)$ 
    else return;
  if  $\neg((\text{font}(l) = \text{font}(r)) \wedge (\text{pdf\_font\_shrink}[\text{font}(l)] \neq \text{null\_font}))$  then return;
   $d \leftarrow \text{get\_kern}(\text{pdf\_font\_shrink}[\text{font}(l)], \text{character}(l), \text{character}(r));$ 
   $\text{kern\_shrink} \leftarrow \text{round\_xn\_over\_d}(\text{width}(p) - d, \text{get\_ef\_code}(\text{font}(l), \text{character}(l)), 1000);$ 
end;

procedure  $\text{do\_subst\_font}(p : \text{pointer}; \text{ex\_ratio} : \text{integer});$ 
  var  $f, k$ : internal\_font\_number;  $r$ : pointer;  $\text{ef}$ : integer;
  begin if  $\neg \text{is\_char\_node}(p) \wedge (\text{type}(p) = \text{disc\_node})$  then
    begin  $r \leftarrow \text{pre\_break}(p);$ 
    while  $r \neq \text{null}$  do
      begin if  $\text{is\_char\_node}(r) \vee (\text{type}(r) = \text{ligature\_node})$  then  $\text{do\_subst\_font}(r, \text{ex\_ratio});$ 
       $r \leftarrow \text{link}(r);$ 
      end;
     $r \leftarrow \text{post\_break}(p);$ 
    while  $r \neq \text{null}$  do
      begin if  $\text{is\_char\_node}(r) \vee (\text{type}(r) = \text{ligature\_node})$  then  $\text{do\_subst\_font}(r, \text{ex\_ratio});$ 

```

```

    r ← link(r);
  end;
return;
end;
if is_char_node(p) then r ← p
else if type(p) = ligature_node then r ← lig_char(p)
  else begin { short_display_n(p, 5); }
    pdf_error("font_expansion", "invalid_node_type");
  end;
f ← font(r); ef ← get_ef_code(f, character(r));
if ef = 0 then return;
if (pdf_font_stretch[f] ≠ null_font) ∧ (ex_ratio > 0) then
  k ← expand_font(f, ext_xn_over_d(ex_ratio * ef, pdf_font_expand_ratio[pdf_font_stretch[f]], 1000000))
else if (pdf_font_shrink[f] ≠ null_font) ∧ (ex_ratio < 0) then
  k ← expand_font(f, ext_xn_over_d(ex_ratio * ef, -pdf_font_expand_ratio[pdf_font_shrink[f]], 1000000))
  else k ← f;
if k ≠ f then
  begin font(r) ← k;
  if ¬is_char_node(p) then
    begin r ← lig_ptr(p);
    while r ≠ null do
      begin font(r) ← k; r ← link(r);
    end;
  end;
end;
end;
function char_pw(p : pointer; side : small_number): scaled;
var f: internal_font_number; c: integer;
begin char_pw ← 0;
if side = left_side then last_leftmost_char ← null
else last_rightmost_char ← null;
if p = null then return;
if ¬is_char_node(p) then
  begin if type(p) = ligature_node then p ← lig_char(p)
  else return;
  end;
f ← font(p);
if side = left_side then
  begin c ← get_lp_code(f, character(p)); last_leftmost_char ← p;
  end
else begin c ← get_rp_code(f, character(p)); last_rightmost_char ← p;
  end;
if c = 0 then return;
char_pw ← round_xn_over_d(quad(f), c, 1000);
end;
function new_margin_kern(w : scaled; p : pointer; side : small_number): pointer;
var k: pointer;
begin k ← get_node(margin_kern_node_size); type(k) ← margin_kern_node; subtype(k) ← side;
width(k) ← w;
if p = null then pdf_error("margin_kerning", "invalid_pointer_to_marginal_char_node");
fast_get_avail(margin_char(k)); character(margin_char(k)) ← character(p);
font(margin_char(k)) ← font(p); new_margin_kern ← k;

```

```

end;
function hpack(p : pointer; w : scaled; m : small_number): pointer;
label reswitch, common_ending, exit;
var r: pointer; { the box node that will be returned }
    q: pointer; { trails behind p }
    h, d, x: scaled; { height, depth, and natural width }
    s: scaled; { shift amount }
    g: pointer; { points to a glue specification }
    o: glue_ord; { order of infinity }
    f: internal_font_number; { the font in a char_node }
    i: four_quarters; { font information about a char_node }
    hd: eight_bits; { height and depth indices for a character }
    font_stretch: scaled; font_shrink: scaled; k: scaled;
begin last_badness  $\leftarrow$  0; r  $\leftarrow$  get_node(box_node_size); type(r)  $\leftarrow$  hlist_node;
    subtype(r)  $\leftarrow$  min_quarterword; shift_amount(r)  $\leftarrow$  0; q  $\leftarrow$  r + list_offset; link(q)  $\leftarrow$  p;
if m = cal_expand_ratio then
    begin prev_char_p  $\leftarrow$  null; font_stretch  $\leftarrow$  0; font_shrink  $\leftarrow$  0; font_expand_ratio  $\leftarrow$  0;
    end;
    h  $\leftarrow$  0; { Clear dimensions to zero 822 };
if TeXXeT_en then { Initialize the LR stack 1707 };
while p  $\neq$  null do { Examine node p in the hlist, taking account of its effect on the dimensions of the
    new box, or moving it to the adjustment list; then advance p to the next node 823 };
if adjust_tail  $\neq$  null then link(adjust_tail)  $\leftarrow$  null;
if pre_adjust_tail  $\neq$  null then link(pre_adjust_tail)  $\leftarrow$  null;
    height(r)  $\leftarrow$  h; depth(r)  $\leftarrow$  d;
    { Determine the value of width(r) and the appropriate glue setting; then return or goto
    common_ending 831 };
common_ending: { Finish issuing a diagnostic message for an overfull or underfull hbox 837 };
exit: if TeXXeT_en then { Check for LR anomalies at the end of hpack 1709 };
if (m = cal_expand_ratio)  $\wedge$  (font_expand_ratio  $\neq$  0) then
    begin font_expand_ratio  $\leftarrow$  fix_int(font_expand_ratio, -1000, 1000); q  $\leftarrow$  list_ptr(r);
    free_node(r, box_node_size); r  $\leftarrow$  hpack(q, w, subst_ex_font);
    end;
    hpack  $\leftarrow$  r;
end;

```

822. { Clear dimensions to zero 822 } \equiv
 $d \leftarrow 0$; $x \leftarrow 0$; $total_stretch[normal] \leftarrow 0$; $total_shrink[normal] \leftarrow 0$; $total_stretch[fil] \leftarrow 0$;
 $total_shrink[fil] \leftarrow 0$; $total_stretch[fill] \leftarrow 0$; $total_shrink[fill] \leftarrow 0$; $total_stretch[filll] \leftarrow 0$;
 $total_shrink[filll] \leftarrow 0$

This code is used in sections 821 and 842.

823. \langle Examine node p in the hlist, taking account of its effect on the dimensions of the new box, or moving it to the adjustment list; then advance p to the next node [823](#) $\rangle \equiv$

```

begin reswitch: while is_char_node(p) do  $\langle$  Incorporate character dimensions into the dimensions of the
    hbox that will contain it, then move to the next node 826  $\rangle$ ;
if  $p \neq \text{null}$  then
  begin case type(p) of
    hlist_node, vlist_node, rule_node, unset_node:  $\langle$  Incorporate box dimensions into the dimensions of the
      hbox that will contain it 825  $\rangle$ ;
    ins_node, mark_node, adjust_node: if (adjust_tail  $\neq$  null)  $\vee$  (pre_adjust_tail  $\neq$  null) then
       $\langle$  Transfer node  $p$  to the adjustment list 829  $\rangle$ ;
    whatsit_node:  $\langle$  Incorporate a whatsit node into an hbox 1604  $\rangle$ ;
    glue_node:  $\langle$  Incorporate glue into the horizontal totals 830  $\rangle$ ;
    margin_kern_node: begin if  $m = \text{cal\_expand\_ratio}$  then
      begin  $f \leftarrow \text{font}(\text{margin\_char}(p))$ ; do_subst_font(margin_char(p), 1000);
      if  $f \neq \text{font}(\text{margin\_char}(p))$  then
        font_stretch  $\leftarrow$  font_stretch  $-$  width(p)  $-$  char_pw(margin_char(p), subtype(p));
        font(margin_char(p))  $\leftarrow$  f; do_subst_font(margin_char(p),  $-1000$ );
      if  $f \neq \text{font}(\text{margin\_char}(p))$  then
        font_shrink  $\leftarrow$  font_shrink  $-$  width(p)  $-$  char_pw(margin_char(p), subtype(p));
        font(margin_char(p))  $\leftarrow$  f;
      end
    else if  $m = \text{subst\_ex\_font}$  then
      begin do_subst_font(margin_char(p), font_expand_ratio);
      width(p)  $\leftarrow$   $-$  char_pw(margin_char(p), subtype(p));
      end;
     $x \leftarrow x + \text{width}(p)$ ;
  end;
  kern_node: begin if subtype(p) = normal then
    begin if  $m = \text{cal\_expand\_ratio}$  then
      begin font_stretch  $\leftarrow$  font_stretch + kern_stretch(p); font_shrink  $\leftarrow$  font_shrink + kern_shrink(p);
      end
    else if  $m = \text{subst\_ex\_font}$  then
      begin if font_expand_ratio  $> 0$  then  $k \leftarrow \text{kern\_stretch}(p)$ 
      else if font_expand_ratio  $< 0$  then  $k \leftarrow \text{kern\_shrink}(p)$ 
      else pdfassert(0);
      if  $k \neq 0$  then
        begin if is_char_node(link(p)) then
          width(p)  $\leftarrow$  get_kern(font(prev_char_p), character(prev_char_p), character(link(p)))
        else if type(link(p)) = ligature_node then width(p)  $\leftarrow$  get_kern(font(prev_char_p),
          character(prev_char_p), character(lig_char(link(p)))));
        end;
      end;
    end;
     $x \leftarrow x + \text{width}(p)$ ;
  end;
  math_node: begin  $x \leftarrow x + \text{width}(p)$ ;
  if TeXXeT_en then  $\langle$  Adjust the LR stack for the hpack routine 1708  $\rangle$ ;
  end;
  ligature_node: begin if  $m = \text{subst\_ex\_font}$  then do_subst_font(p, font_expand_ratio);
   $\langle$  Make node  $p$  look like a char_node and goto reswitch 824  $\rangle$ ;
  end;
  disc_node: if  $m = \text{subst\_ex\_font}$  then do_subst_font(p, font_expand_ratio);

```

```

    othercases do_nothing
endcases;


← link(p);
end;
end


```

This code is used in section 821.

824. \langle Make node *p* look like a *char_node* and **goto** *reswitch* 824 $\rangle \equiv$

```

begin mem[lig_trick] ← mem[lig_char(p)]; link(lig_trick) ← link(p); p ← lig_trick; goto reswitch;
end

```

This code is used in sections 650, 732, 823, and 1323.

825. The code here implicitly uses the fact that running dimensions are indicated by *null_flag*, which will be ignored in the calculations because it is a highly negative number.

\langle Incorporate box dimensions into the dimensions of the hbox that will contain it 825 $\rangle \equiv$

```

begin x ← x + width(p);
if type(p) ≥ rule_node then s ← 0 else s ← shift_amount(p);
if height(p) − s > h then h ← height(p) − s;
if depth(p) + s > d then d ← depth(p) + s;
end

```

This code is used in section 823.

826. The following code is part of TeX's inner loop; i.e., adding another character of text to the user's input will cause each of these instructions to be exercised one more time.

\langle Incorporate character dimensions into the dimensions of the hbox that will contain it, then move to the next node 826 $\rangle \equiv$

```

begin if m ≥ cal_expand_ratio then
  begin prev_char_p ← p;
  case m of
    cal_expand_ratio: begin f ← font(p); add_char_stretch(font_stretch)(character(p));
      add_char_shrink(font_shrink)(character(p));
    end;
    subst_ex_font: do_subst_font(p, font_expand_ratio);
  endcases;
end;
f ← font(p); i ← char_info(f)(character(p)); hd ← height_depth(i); x ← x + char_width(f)(i);
s ← char_height(f)(hd); if s > h then h ← s;
s ← char_depth(f)(hd); if s > d then d ← s;


← link(p);
end


```

This code is used in section 823.

827. Although node *q* is not necessarily the immediate predecessor of node *p*, it always points to some node in the list preceding *p*. Thus, we can delete nodes by moving *q* when necessary. The algorithm takes linear time, and the extra computation does not intrude on the inner loop unless it is necessary to make a deletion.

\langle Global variables 13 $\rangle + \equiv$

```

pre_adjust_tail: pointer;

```

828. \langle Set initial values of key variables 21 $\rangle + \equiv$

```

pre_adjust_tail ← null;

```

829. Materials in `\vadjust` used with `pre` keyword will be appended to *pre_adjust_tail* instead of *adjust_tail*.■

```

define update_adjust_list(#) ≡
  begin if # = null then confusion("pre_vadjust");
  link(#) ← adjust_ptr(p);
  while link(#) ≠ null do # ← link(#);
  end

⟨Transfer node p to the adjustment list 829⟩ ≡
begin while link(q) ≠ p do q ← link(q);
if type(p) = adjust_node then
  begin if adjust_pre(p) ≠ 0 then update_adjust_list(pre_adjust_tail)
  else update_adjust_list(adjust_tail);
  p ← link(p); free_node(link(q), small_node_size);
  end
else begin link(adjust_tail) ← p; adjust_tail ← p; p ← link(p);
  end;
link(q) ← p; p ← q;
end

```

This code is used in section 823.

830. ⟨Incorporate glue into the horizontal totals 830⟩ ≡

```

begin g ← glue_ptr(p); x ← x + width(g);
o ← stretch_order(g); total_stretch[o] ← total_stretch[o] + stretch(g); o ← shrink_order(g);
total_shrink[o] ← total_shrink[o] + shrink(g);
if subtype(p) ≥ a_leaders then
  begin g ← leader_ptr(p);
  if height(g) > h then h ← height(g);
  if depth(g) > d then d ← depth(g);
  end;
end

```

This code is used in section 823.

831. When we get to the present part of the program, *x* is the natural width of the box being packaged.

⟨Determine the value of *width*(*r*) and the appropriate glue setting; then **return** or **goto** *common_ending* 831⟩ ≡

```

if m = additional then w ← x + w;
width(r) ← w; x ← w - x; { now x is the excess to be made up }
if x = 0 then
  begin glue_sign(r) ← normal; glue_order(r) ← normal; set_glue_ratio_zero(glue_set(r)); return;
  end
else if x > 0 then
  ⟨Determine horizontal glue stretch setting, then return or goto common_ending 832⟩
  else ⟨Determine horizontal glue shrink setting, then return or goto common_ending 838⟩

```

This code is used in section 821.

832. If *hpack* is called with $m = \text{cal_expand_ratio}$ we calculate *font_expand_ratio* and return without checking for overfull or underfull box.

```

⟨Determine horizontal glue stretch setting, then return or goto common_ending 832⟩ ≡
  begin ⟨Determine the stretch order 833⟩;
  if ( $m = \text{cal\_expand\_ratio}$ )  $\wedge$  ( $o = \text{normal}$ )  $\wedge$  ( $\text{font\_stretch} > 0$ ) then
    begin  $\text{font\_expand\_ratio} \leftarrow \text{divide\_scaled}(x, \text{font\_stretch}, 3)$ ; return;
    end;
   $\text{glue\_order}(r) \leftarrow o$ ;  $\text{glue\_sign}(r) \leftarrow \text{stretching}$ ;
  if  $\text{total\_stretch}[o] \neq 0$  then  $\text{glue\_set}(r) \leftarrow \text{unfloat}(x/\text{total\_stretch}[o])$ 
  else begin  $\text{glue\_sign}(r) \leftarrow \text{normal}$ ;  $\text{set\_glue\_ratio\_zero}(\text{glue\_set}(r))$ ; { there's nothing to stretch }
    end;
  if  $o = \text{normal}$  then
    if  $\text{list\_ptr}(r) \neq \text{null}$  then
      ⟨Report an underfull hbox and goto common_ending, if this box is sufficiently bad 834⟩;
  return;
end

```

This code is used in section 831.

833. ⟨Determine the stretch order 833⟩ ≡

```

if  $\text{total\_stretch}[\text{fill}] \neq 0$  then  $o \leftarrow \text{fill}$ 
else if  $\text{total\_stretch}[\text{fill}] \neq 0$  then  $o \leftarrow \text{fill}$ 
  else if  $\text{total\_stretch}[\text{fil}] \neq 0$  then  $o \leftarrow \text{fil}$ 
  else  $o \leftarrow \text{normal}$ 

```

This code is used in sections 832, 847, and 970.

834. ⟨Report an underfull hbox and **goto** *common_ending*, if this box is sufficiently bad 834⟩ ≡

```

begin  $\text{last\_badness} \leftarrow \text{badness}(x, \text{total\_stretch}[\text{normal}])$ ;
if  $\text{last\_badness} > \text{hbadness}$  then
  begin  $\text{print\_ln}$ ;
  if  $\text{last\_badness} > 100$  then  $\text{print\_nl}(\text{"Underfull"})$  else  $\text{print\_nl}(\text{"Loose"})$ ;
   $\text{print}(\text{"\hbox{ "badness "});$   $\text{print\_int}(\text{last\_badness})$ ; goto common_ending;
  end;
end

```

This code is used in section 832.

835. In order to provide a decent indication of where an overfull or underfull box originated, we use a global variable *pack_begin_line* that is set nonzero only when *hpack* is being called by the paragraph builder or the alignment finishing routine.

```

⟨Global variables 13⟩ +=
 $\text{pack\_begin\_line}$ : integer; { source file line where the current paragraph or alignment began; a negative
  value denotes alignment }

```

836. ⟨Set initial values of key variables 21⟩ +=

```

 $\text{pack\_begin\_line} \leftarrow 0$ ;

```

837. \langle Finish issuing a diagnostic message for an overfull or underfull hbox [837](#) $\rangle \equiv$

```

if output_active then print(")\_has\_occurred\_while\_output\_is\_active")
else begin if pack_begin_line  $\neq$  0 then
  begin if pack_begin_line > 0 then print(")\_in\_paragraph\_at\_lines\_")
  else print(")\_in\_alignment\_at\_lines\_");
  print_int(abs(pack_begin_line)); print("--");
  end
else print(")\_detected\_at\_line\_");
  print_int(line);
end;
print_ln;
font_in_short_display  $\leftarrow$  null_font; short_display(list_ptr(r)); print_ln;
begin_diagnostic; show_box(r); end_diagnostic(true)

```

This code is used in section [821](#).

838. \langle Determine horizontal glue shrink setting, then **return** or **goto** *common_ending* [838](#) $\rangle \equiv$

```

begin  $\langle$  Determine the shrink order 839  $\rangle$ ;
if (m = cal_expand_ratio)  $\wedge$  (o = normal)  $\wedge$  (font_shrink > 0) then
  begin font_expand_ratio  $\leftarrow$  divide_scaled(x, font_shrink, 3); return;
end;
glue_order(r)  $\leftarrow$  o; glue_sign(r)  $\leftarrow$  shrinking;
if total_shrink[o]  $\neq$  0 then glue_set(r)  $\leftarrow$  unfloat((-x)/total_shrink[o])
else begin glue_sign(r)  $\leftarrow$  normal; set_glue_ratio_zero(glue_set(r)); { there's nothing to shrink }
end;
if (total_shrink[o] < -x)  $\wedge$  (o = normal)  $\wedge$  (list_ptr(r)  $\neq$  null) then
  begin last_badness  $\leftarrow$  1000000; set_glue_ratio_one(glue_set(r)); { use the maximum shrinkage }
   $\langle$  Report an overfull hbox and goto common_ending, if this box is sufficiently bad 840  $\rangle$ ;
end
else if o = normal then
  if list_ptr(r)  $\neq$  null then
     $\langle$  Report a tight hbox and goto common_ending, if this box is sufficiently bad 841  $\rangle$ ;
return;
end

```

This code is used in section [831](#).

839. \langle Determine the shrink order [839](#) $\rangle \equiv$

```

if total_shrink[filll]  $\neq$  0 then o  $\leftarrow$  filll
else if total_shrink[fill]  $\neq$  0 then o  $\leftarrow$  fill
else if total_shrink[fil]  $\neq$  0 then o  $\leftarrow$  fil
else o  $\leftarrow$  normal

```

This code is used in sections [838](#), [850](#), and [970](#).

840. \langle Report an overfull hbox and **goto** *common_ending*, if this box is sufficiently bad [840](#) $\rangle \equiv$

```

if (-x - total_shrink[normal] > hfuzz)  $\vee$  (hbadness < 100) then
  begin if (overfull_rule > 0)  $\wedge$  (-x - total_shrink[normal] > hfuzz) then
    begin while link(q)  $\neq$  null do q  $\leftarrow$  link(q);
    link(q)  $\leftarrow$  new_rule; width(link(q))  $\leftarrow$  overfull_rule;
    end;
  print_ln; print_nl("Overfull\_hbox\_"); print_scaled(-x - total_shrink[normal]);
  print("pt\_too\_wide"); goto common_ending;
end

```

This code is used in section [838](#).

841. \langle Report a tight hbox and **goto** *common_ending*, if this box is sufficiently bad 841 $\rangle \equiv$
begin *last_badness* \leftarrow *badness*($-x$, *total_shrink*[*normal*]);
if *last_badness* $>$ *hbadness* **then**
 begin *print_ln*; *print_nl*("Tight\hbox(*badness*)"); *print_int*(*last_badness*); **goto** *common_ending*;
 end;
end

This code is used in section 838.

842. The *vpack* subroutine is actually a special case of a slightly more general routine called *vpackage*, which has four parameters. The fourth parameter, which is *max_dimen* in the case of *vpack*, specifies the maximum depth of the page box that is constructed. The depth is first computed by the normal rules; if it exceeds this limit, the reference point is simply moved down until the limiting depth is attained.

define *vpack*(#) \equiv *vpackage*(#, *max_dimen*) { special case of unconstrained depth }
function *vpackage*(*p* : *pointer*; *h* : *scaled*; *m* : *small_number*; *l* : *scaled*): *pointer*;
 label *common_ending*, *exit*;
 var *r* : *pointer*; { the box node that will be returned }
 w, *d*, *x* : *scaled*; { width, depth, and natural height }
 s : *scaled*; { shift amount }
 g : *pointer*; { points to a glue specification }
 o : *glue_ord*; { order of infinity }
 begin *last_badness* \leftarrow 0; *r* \leftarrow *get_node*(*box_node_size*); *type*(*r*) \leftarrow *vlist_node*;
 subtype(*r*) \leftarrow *min_quarterword*; *shift_amount*(*r*) \leftarrow 0; *list_ptr*(*r*) \leftarrow *p*;
 w \leftarrow 0; \langle Clear dimensions to zero 822 \rangle ;
 while *p* \neq *null* **do** \langle Examine node *p* in the vlist, taking account of its effect on the dimensions of the
 new box; then advance *p* to the next node 843 \rangle ;
 width(*r*) \leftarrow *w*;
 if *d* $>$ *l* **then**
 begin *x* \leftarrow *x* + *d* - *l*; *depth*(*r*) \leftarrow *l*;
 end
 else *depth*(*r*) \leftarrow *d*;
 \langle Determine the value of *height*(*r*) and the appropriate glue setting; then **return** or **goto**
 common_ending 846 \rangle ;
common_ending: \langle Finish issuing a diagnostic message for an overfull or underfull vbox 849 \rangle ;
 exit: *vpackage* \leftarrow *r*;
 end;

843. \langle Examine node *p* in the vlist, taking account of its effect on the dimensions of the new box; then
 advance *p* to the next node 843 $\rangle \equiv$
 begin **if** *is_char_node*(*p*) **then** *confusion*("vpack")
 else case *type*(*p*) **of**
 hlist_node, *vlist_node*, *rule_node*, *unset_node*: \langle Incorporate box dimensions into the dimensions of the
 vbox that will contain it 844 \rangle ;
 whatsit_node: \langle Incorporate a whatsit node into a vbox 1603 \rangle ;
 glue_node: \langle Incorporate glue into the vertical totals 845 \rangle ;
 kern_node: **begin** *x* \leftarrow *x* + *d* + *width*(*p*); *d* \leftarrow 0;
 end;
 othercases *do_nothing*
 endcases;
 p \leftarrow *link*(*p*);
 end

This code is used in section 842.

844. \langle Incorporate box dimensions into the dimensions of the vbox that will contain it [844](#) $\rangle \equiv$
begin $x \leftarrow x + d + \text{height}(p)$; $d \leftarrow \text{depth}(p)$;
if $\text{type}(p) \geq \text{rule_node}$ **then** $s \leftarrow 0$ **else** $s \leftarrow \text{shift_amount}(p)$;
if $\text{width}(p) + s > w$ **then** $w \leftarrow \text{width}(p) + s$;
end

This code is used in section [843](#).

845. \langle Incorporate glue into the vertical totals [845](#) $\rangle \equiv$
begin $x \leftarrow x + d$; $d \leftarrow 0$;
 $g \leftarrow \text{glue_ptr}(p)$; $x \leftarrow x + \text{width}(g)$;
 $o \leftarrow \text{stretch_order}(g)$; $\text{total_stretch}[o] \leftarrow \text{total_stretch}[o] + \text{stretch}(g)$; $o \leftarrow \text{shrink_order}(g)$;
 $\text{total_shrink}[o] \leftarrow \text{total_shrink}[o] + \text{shrink}(g)$;
if $\text{subtype}(p) \geq a_leaders$ **then**
 begin $g \leftarrow \text{leader_ptr}(p)$;
 if $\text{width}(g) > w$ **then** $w \leftarrow \text{width}(g)$;
 end;
end

This code is used in section [843](#).

846. When we get to the present part of the program, x is the natural height of the box being packaged.
 \langle Determine the value of $\text{height}(r)$ and the appropriate glue setting; then **return** or **goto** *common_ending* [846](#) $\rangle \equiv$
if $m = \text{additional}$ **then** $h \leftarrow x + h$;
 $\text{height}(r) \leftarrow h$; $x \leftarrow h - x$; { now x is the excess to be made up }
if $x = 0$ **then**
 begin $\text{glue_sign}(r) \leftarrow \text{normal}$; $\text{glue_order}(r) \leftarrow \text{normal}$; $\text{set_glue_ratio_zero}(\text{glue_set}(r))$; **return**;
 end
else if $x > 0$ **then** \langle Determine vertical glue stretch setting, then **return** or **goto** *common_ending* [847](#) \rangle
 else \langle Determine vertical glue shrink setting, then **return** or **goto** *common_ending* [850](#) \rangle

This code is used in section [842](#).

847. \langle Determine vertical glue stretch setting, then **return** or **goto** *common_ending* [847](#) $\rangle \equiv$
begin \langle Determine the stretch order [833](#) \rangle ;
 $\text{glue_order}(r) \leftarrow o$; $\text{glue_sign}(r) \leftarrow \text{stretching}$;
if $\text{total_stretch}[o] \neq 0$ **then** $\text{glue_set}(r) \leftarrow \text{unfloat}(x / \text{total_stretch}[o])$
else begin $\text{glue_sign}(r) \leftarrow \text{normal}$; $\text{set_glue_ratio_zero}(\text{glue_set}(r))$; { there's nothing to stretch }
 end;
if $o = \text{normal}$ **then**
 if $\text{list_ptr}(r) \neq \text{null}$ **then**
 \langle Report an underfull vbox and **goto** *common_ending*, if this box is sufficiently bad [848](#) \rangle ;
 return;
end

This code is used in section [846](#).

848. \langle Report an underfull vbox and **goto** *common_ending*, if this box is sufficiently bad [848](#) $\rangle \equiv$

```

begin last_badness  $\leftarrow$  badness(x, total_stretch[normal]);
if last_badness > vbadness then
  begin print_ln;
  if last_badness > 100 then print_nl("Underfull") else print_nl("Loose");
  print("_\vbox_(badness_"); print_int(last_badness); goto common_ending;
end;
end

```

This code is used in section [847](#).

849. \langle Finish issuing a diagnostic message for an overfull or underfull vbox [849](#) $\rangle \equiv$

```

if output_active then print("_has_occurred_while_output_is_active")
else begin if pack_begin_line  $\neq$  0 then { it's actually negative }
  begin print("_in_alignment_at_lines_"); print_int(abs(pack_begin_line)); print("--");
  end
  else print("_detected_at_line_");
  print_int(line); print_ln;
end;
begin_diagnostic; show_box(r); end_diagnostic(true)

```

This code is used in section [842](#).

850. \langle Determine vertical glue shrink setting, then **return** or **goto** *common_ending* [850](#) $\rangle \equiv$

```

begin  $\langle$  Determine the shrink order 839  $\rangle$ ;
glue_order(r)  $\leftarrow$  o; glue_sign(r)  $\leftarrow$  shrinking;
if total_shrink[o]  $\neq$  0 then glue_set(r)  $\leftarrow$  unfloat((-x)/total_shrink[o])
else begin glue_sign(r)  $\leftarrow$  normal; set_glue_ratio_zero(glue_set(r)); { there's nothing to shrink }
  end;
if (total_shrink[o] < -x)  $\wedge$  (o = normal)  $\wedge$  (list_ptr(r)  $\neq$  null) then
  begin last_badness  $\leftarrow$  1000000; set_glue_ratio_one(glue_set(r)); { use the maximum shrinkage }
   $\langle$  Report an overfull vbox and goto common_ending, if this box is sufficiently bad 851  $\rangle$ ;
  end
else if o = normal then
  if list_ptr(r)  $\neq$  null then
     $\langle$  Report a tight vbox and goto common_ending, if this box is sufficiently bad 852  $\rangle$ ;
return;
end

```

This code is used in section [846](#).

851. \langle Report an overfull vbox and **goto** *common_ending*, if this box is sufficiently bad [851](#) $\rangle \equiv$

```

if (-x - total_shrink[normal] > vfuzz)  $\vee$  (vbadness < 100) then
  begin print_ln; print_nl("Overfull_\vbox_"); print_scaled(-x - total_shrink[normal]);
  print("pt_too_high"); goto common_ending;
end

```

This code is used in section [850](#).

852. \langle Report a tight vbox and **goto** *common_ending*, if this box is sufficiently bad [852](#) $\rangle \equiv$

```

begin last_badness  $\leftarrow$  badness(-x, total_shrink[normal]);
if last_badness > vbadness then
  begin print_ln; print_nl("Tight_\vbox_(badness_"); print_int(last_badness); goto common_ending;
  end;
end

```

This code is used in section [850](#).

853. When a box is being appended to the current vertical list, the baselineskip calculation is handled by the *append_to_vlist* routine.

```

procedure append_to_vlist(b : pointer);
  var d: scaled; { deficiency of space between baselines }
      p: pointer; { a new glue node }
  begin if prev_depth > pdf_ignored_dimen then
    begin d  $\leftarrow$  width(baseline_skip) - prev_depth - height(b);
    if d < line_skip_limit then p  $\leftarrow$  new_param_glue(line_skip_code)
    else begin p  $\leftarrow$  new_skip_param(baseline_skip_code); width(temp_ptr)  $\leftarrow$  d;
      { temp_ptr = glue_ptr(p) }
    end;
    link(tail)  $\leftarrow$  p; tail  $\leftarrow$  p;
  end;
  link(tail)  $\leftarrow$  b; tail  $\leftarrow$  b; prev_depth  $\leftarrow$  depth(b);
end;

```

854. Data structures for math mode. When T_EX reads a formula that is enclosed between \$’s, it constructs an *m*list, which is essentially a tree structure representing that formula. An *m*list is a linear sequence of items, but we can regard it as a tree structure because *m*lists can appear within *m*lists. For example, many of the entries can be subscripted or superscripted, and such “scripts” are *m*lists in their own right.

An entire formula is parsed into such a tree before any of the actual typesetting is done, because the current style of type is usually not known until the formula has been fully scanned. For example, when the formula ‘`$a+b \over c+d$`’ is being read, there is no way to tell that ‘`a+b`’ will be in script size until ‘`\over`’ has appeared.

During the scanning process, each element of the *m*list being built is classified as a relation, a binary operator, an open parenthesis, etc., or as a construct like ‘`\sqrt`’ that must be built up. This classification appears in the *m*list data structure.

After a formula has been fully scanned, the *m*list is converted to an *h*list so that it can be incorporated into the surrounding text. This conversion is controlled by a recursive procedure that decides all of the appropriate styles by a “top-down” process starting at the outermost level and working in towards the subformulas. The formula is ultimately pasted together using combinations of horizontal and vertical boxes, with glue and penalty nodes inserted as necessary.

An *m*list is represented internally as a linked list consisting chiefly of “noads” (pronounced “no-adds”), to distinguish them from the somewhat similar “nodes” in *h*lists and *v*lists. Certain kinds of ordinary nodes are allowed to appear in *m*lists together with the noads; T_EX tells the difference by means of the *type* field, since a noad’s *type* is always greater than that of a node. An *m*list does not contain character nodes, *h*list nodes, *v*list nodes, math nodes, ligature nodes, or unset nodes; in particular, each *m*list item appears in the variable-size part of *mem*, so the *type* field is always present.

855. Each noad is four or more words long. The first word contains the *type* and *subtype* and *link* fields that are already so familiar to us; the second, third, and fourth words are called the noad’s *nucleus*, *subscr*, and *supscr* fields.

Consider, for example, the simple formula ‘ x^2 ’, which would be parsed into an mlist containing a single element called an *ord_noad*. The *nucleus* of this noad is a representation of ‘ x ’, the *subscr* is empty, and the *supscr* is a representation of ‘2’.

The *nucleus*, *subscr*, and *supscr* fields are further broken into subfields. If p points to a noad, and if q is one of its principal fields (e.g., $q = \text{subscr}(p)$), there are several possibilities for the subfields, depending on the *math_type* of q .

$\text{math_type}(q) = \text{math_char}$ means that $\text{fam}(q)$ refers to one of the sixteen font families, and $\text{character}(q)$ is the number of a character within a font of that family, as in a character node.

$\text{math_type}(q) = \text{math_text_char}$ is similar, but the character is unsubscripted and unsuperscripted and it is followed immediately by another character from the same font. (This *math_type* setting appears only briefly during the processing; it is used to suppress unwanted italic corrections.)

$\text{math_type}(q) = \text{empty}$ indicates a field with no value (the corresponding attribute of noad p is not present).

$\text{math_type}(q) = \text{sub_box}$ means that $\text{info}(q)$ points to a box node (either an *hlist_node* or a *vlist_node*) that should be used as the value of the field. The *shift_amount* in the subsidiary box node is the amount by which that box will be shifted downward.

$\text{math_type}(q) = \text{sub_mlist}$ means that $\text{info}(q)$ points to an mlist; the mlist must be converted to an hlist in order to obtain the value of this field.

In the latter case, we might have $\text{info}(q) = \text{null}$. This is not the same as $\text{math_type}(q) = \text{empty}$; for example, ‘ $P_{\{ \}}$ ’ and ‘ P_P ’ produce different results (the former will not have the “italic correction” added to the width of P , but the “script skip” will be added).

The definitions of subfields given here are evidently wasteful of space, since a halfword is being used for the *math_type* although only three bits would be needed. However, there are hardly ever many noads present at once, since they are soon converted to nodes that take up even more space, so we can afford to represent them in whatever way simplifies the programming.

```

define noad_size = 4    { number of words in a normal noad }
define nucleus(#)  $\equiv$  # + 1 { the nucleus field of a noad }
define supscr(#)  $\equiv$  # + 2  { the supscr field of a noad }
define subscr(#)  $\equiv$  # + 3  { the subscr field of a noad }
define math_type  $\equiv$  link  { a halfword in mem }
define fam  $\equiv$  font      { a quarterword in mem }
define math_char = 1    { math_type when the attribute is simple }
define sub_box = 2      { math_type when the attribute is a box }
define sub_mlist = 3    { math_type when the attribute is a formula }
define math_text_char = 4 { math_type when italic correction is dubious }

```

856. Each portion of a formula is classified as Ord, Op, Bin, Rel, Open, Close, Punct, or Inner, for purposes of spacing and line breaking. An *ord_noad*, *op_noad*, *bin_noad*, *rel_noad*, *open_noad*, *close_noad*, *punct_noad*, or *inner_noad* is used to represent portions of the various types. For example, an ‘=’ sign in a formula leads to the creation of a *rel_noad* whose *nucleus* field is a representation of an equals sign (usually *fam* = 0, *character* = ‘75’). A formula preceded by `\mathrel` also results in a *rel_noad*. When a *rel_noad* is followed by an *op_noad*, say, and possibly separated by one or more ordinary nodes (not noads), TeX will insert a penalty node (with the current *rel_penalty*) just after the formula that corresponds to the *rel_noad*, unless there already was a penalty immediately following; and a “thick space” will be inserted just before the formula that corresponds to the *op_noad*.

A noad of type *ord_noad*, *op_noad*, ..., *inner_noad* usually has a *subtype* = *normal*. The only exception is that an *op_noad* might have *subtype* = *limits* or *no_limits*, if the normal positioning of limits has been overridden for this operator.

```

define ord_noad = unset_node + 3 { type of a noad classified Ord }
define op_noad = ord_noad + 1 { type of a noad classified Op }
define bin_noad = ord_noad + 2 { type of a noad classified Bin }
define rel_noad = ord_noad + 3 { type of a noad classified Rel }
define open_noad = ord_noad + 4 { type of a noad classified Open }
define close_noad = ord_noad + 5 { type of a noad classified Close }
define punct_noad = ord_noad + 6 { type of a noad classified Punct }
define inner_noad = ord_noad + 7 { type of a noad classified Inner }
define limits = 1 { subtype of op_noad whose scripts are to be above, below }
define no_limits = 2 { subtype of op_noad whose scripts are to be normal }

```

857. A *radical_noad* is five words long; the fifth word is the *left_delimiter* field, which usually represents a square root sign.

A *fraction_noad* is six words long; it has a *right_delimiter* field as well as a *left_delimiter*.

Delimiter fields are of type *four_quarters*, and they have four subfields called *small_fam*, *small_char*, *large_fam*, *large_char*. These subfields represent variable-size delimiters by giving the “small” and “large” starting characters, as explained in Chapter 17 of *The TeXbook*.

A *fraction_noad* is actually quite different from all other noads. Not only does it have six words, it has *thickness*, *denominator*, and *numerator* fields instead of *nucleus*, *subscr*, and *supscr*. The *thickness* is a scaled value that tells how thick to make a fraction rule; however, the special value *default_code* is used to stand for the *default_rule_thickness* of the current size. The *numerator* and *denominator* point to mlists that define a fraction; we always have

$$\mathit{math_type}(\mathit{numerator}) = \mathit{math_type}(\mathit{denominator}) = \mathit{sub_mlist}.$$

The *left_delimiter* and *right_delimiter* fields specify delimiters that will be placed at the left and right of the fraction. In this way, a *fraction_noad* is able to represent all of TeX’s operators `\over`, `\atop`, `\above`, `\overwithdelims`, `\atopwithdelims`, and `\abovewithdelims`.

```

define left_delimiter(#) ≡ # + 4 { first delimiter field of a noad }
define right_delimiter(#) ≡ # + 5 { second delimiter field of a fraction noad }
define radical_noad = inner_noad + 1 { type of a noad for square roots }
define radical_noad_size = 5 { number of mem words in a radical noad }
define fraction_noad = radical_noad + 1 { type of a noad for generalized fractions }
define fraction_noad_size = 6 { number of mem words in a fraction noad }
define small_fam(#) ≡ mem[#].qqqq.b0 { fam for “small” delimiter }
define small_char(#) ≡ mem[#].qqqq.b1 { character for “small” delimiter }
define large_fam(#) ≡ mem[#].qqqq.b2 { fam for “large” delimiter }
define large_char(#) ≡ mem[#].qqqq.b3 { character for “large” delimiter }
define thickness ≡ width { thickness field in a fraction noad }
define default_code ≡ '10000000000 { denotes default_rule_thickness }
define numerator ≡ supscr { numerator field in a fraction noad }
define denominator ≡ subscr { denominator field in a fraction noad }

```

858. The global variable *empty_field* is set up for initialization of empty fields in new noads. Similarly, *null_delimiter* is for the initialization of delimiter fields.

⟨Global variables 13⟩ +≡

empty_field: *two_halves*;

null_delimiter: *four_quarters*;

859. ⟨Set initial values of key variables 21⟩ +≡

```

empty_field.rh ← empty; empty_field.lh ← null;
null_delimiter.b0 ← 0; null_delimiter.b1 ← min_quarterword;
null_delimiter.b2 ← 0; null_delimiter.b3 ← min_quarterword;

```

860. The *new_noad* function creates an *ord_noad* that is completely null.

function *new_noad*: *pointer*;

```

var p: pointer;
begin p ← get_node(noad_size); type(p) ← ord_noad; subtype(p) ← normal;
mem[nucleus(p)].hh ← empty_field; mem[subscr(p)].hh ← empty_field;
mem[supscr(p)].hh ← empty_field; new_noad ← p;
end;

```

861. A few more kinds of noads will complete the set: An *under_noad* has its nucleus underlined; an *over_noad* has it overlined. An *accent_noad* places an accent over its nucleus; the accent character appears as $\text{fam}(\text{accent_chr}(p))$ and $\text{character}(\text{accent_chr}(p))$. A *vcenter_noad* centers its nucleus vertically with respect to the axis of the formula; in such noads we always have $\text{math_type}(\text{nucleus}(p)) = \text{sub_box}$.

And finally, we have *left_noad* and *right_noad* types, to implement TeX's `\left` and `\right` as well as ε -TeX's `\middle`. The *nucleus* of such noads is replaced by a *delimiter* field; thus, for example, `\left('` produces a *left_noad* such that $\text{delimiter}(p)$ holds the family and character codes for all left parentheses. A *left_noad* never appears in an mlist except as the first element, and a *right_noad* never appears in an mlist except as the last element; furthermore, we either have both a *left_noad* and a *right_noad*, or neither one is present. The *subscr* and *supscr* fields are always *empty* in a *left_noad* and a *right_noad*.

```

define under_noad = fraction_noad + 1 { type of a noad for underlining }
define over_noad = under_noad + 1 { type of a noad for overlining }
define accent_noad = over_noad + 1 { type of a noad for accented subformulas }
define accent_noad_size = 5 { number of mem words in an accent noad }
define accent_chr(#)  $\equiv$  # + 4 { the accent_chr field of an accent noad }
define vcenter_noad = accent_noad + 1 { type of a noad for \vcenter }
define left_noad = vcenter_noad + 1 { type of a noad for \left }
define right_noad = left_noad + 1 { type of a noad for \right }
define delimiter  $\equiv$  nucleus { delimiter field in left and right noads }
define middle_noad  $\equiv$  1 { subtype of right noad representing \middle }
define scripts_allowed(#)  $\equiv (\text{type}(\#) \geq \text{ord\_noad}) \wedge (\text{type}(\#) < \text{left\_noad})$ 

```

862. Math formulas can also contain instructions like `\textstyle` that override TeX's normal style rules. A *style_node* is inserted into the data structure to record such instructions; it is three words long, so it is considered a node instead of a noad. The *subtype* is either *display_style* or *text_style* or *script_style* or *script_script_style*. The second and third words of a *style_node* are not used, but they are present because a *choice_node* is converted to a *style_node*.

TeX uses even numbers 0, 2, 4, 6 to encode the basic styles *display_style*, ..., *script_script_style*, and adds 1 to get the “cramped” versions of these styles. This gives a numerical order that is backwards from the convention of Appendix G in *The TeXbook*; i.e., a smaller style has a larger numerical value.

```

define style_node = unset_node + 1 { type of a style node }
define style_node_size = 3 { number of words in a style node }
define display_style = 0 { subtype for \displaystyle }
define text_style = 2 { subtype for \textstyle }
define script_style = 4 { subtype for \scriptstyle }
define script_script_style = 6 { subtype for \scriptscriptstyle }
define cramped = 1 { add this to an uncramped style if you want to cramp it }

function new_style(s : small_number): pointer; { create a style node }
var p: pointer; { the new node }
begin p  $\leftarrow$  get_node(style_node_size); type(p)  $\leftarrow$  style_node; subtype(p)  $\leftarrow$  s; width(p)  $\leftarrow$  0;
depth(p)  $\leftarrow$  0; { the width and depth are not used }
new_style  $\leftarrow$  p;
end;

```

863. Finally, the `\mathchoice` primitive creates a *choice_node*, which has special subfields *display_mlist*, *text_mlist*, *script_mlist*, and *script_script_mlist* pointing to the mlists for each style.

```

define choice_node = unset_node + 2 { type of a choice node }
define display_mlist(#) ≡ info(# + 1) { mlist to be used in display style }
define text_mlist(#) ≡ link(# + 1) { mlist to be used in text style }
define script_mlist(#) ≡ info(# + 2) { mlist to be used in script style }
define script_script_mlist(#) ≡ link(# + 2) { mlist to be used in scriptscript style }

function new_choice: pointer; { create a choice node }
var p: pointer; { the new node }
begin p ← get_node(style_node_size); type(p) ← choice_node; subtype(p) ← 0;
      { the subtype is not used }
      display_mlist(p) ← null; text_mlist(p) ← null; script_mlist(p) ← null; script_script_mlist(p) ← null;
      new_choice ← p;
end;

```

864. Let's consider now the previously unwritten part of *show_node_list* that displays the things that can only be present in mlists; this program illustrates how to access the data structures just defined.

In the context of the following program, *p* points to a node or noad that should be displayed, and the current string contains the “recursion history” that leads to this point. The recursion history consists of a dot for each outer level in which *p* is subsidiary to some node, or in which *p* is subsidiary to the *nucleus* field of some noad; the dot is replaced by ‘_’ or ‘^’ or ‘/’ or ‘\’ if *p* is descended from the *subscr* or *supscr* or *denominator* or *numerator* fields of noads. For example, the current string would be ‘.^._/’ if *p* points to the *ord_noad* for *x* in the (ridiculous) formula ‘ $\sqrt{a^{\frac{b}{c}}}$ ’.

⟨Cases of *show_node_list* that arise in mlists only 864⟩ ≡

```

style_node: print_style(subtype(p));
choice_node: ⟨Display choice node p 869⟩;
ord_noad, op_noad, bin_noad, rel_noad, open_noad, close_noad, punct_noad,
inner_noad, radical_noad, over_noad, under_noad, vcenter_noad, accent_noad, left_noad, right_noad:
  ⟨Display normal noad p 870⟩;
fraction_noad: ⟨Display fraction noad p 871⟩;

```

This code is used in section 201.

865. Here are some simple routines used in the display of noads.

⟨Declare procedures needed for displaying the elements of mlists 865⟩ ≡

```

procedure print_fam_and_char(p: pointer); { prints family and character }
begin print_esc("fam"); print_int(fam(p)); print_char("␣"); print_ASCII(qo(character(p)));
end;

procedure print_delimiter(p: pointer); { prints a delimiter as 24-bit hex value }
var a: integer; { accumulator }
begin a ← small_fam(p) * 256 + qo(small_char(p));
      a ← a * 1000 + large_fam(p) * 256 + qo(large_char(p));
      if a < 0 then print_int(a) { this should never happen }
      else print_hex(a);
end;

```

See also sections 866 and 868.

This code is used in section 197.

866. The next subroutine will descend to another level of recursion when a subsidiary mlist needs to be displayed. The parameter c indicates what character is to become part of the recursion history. An empty mlist is distinguished from a field with $math_type(p) = empty$, because these are not equivalent (as explained above).

```

⟨Declare procedures needed for displaying the elements of mlists 865⟩ +=
procedure show_info; forward; { show_node_list(info(temp_ptr)) }
procedure print_subsidary_data( $p$  : pointer;  $c$  : ASCII_code); { display a noad field }
  begin if cur_length ≥ depth_threshold then
    begin if  $math\_type(p) \neq empty$  then print("□□");
    end
  else begin append_char( $c$ ); { include  $c$  in the recursion history }
    temp_ptr ←  $p$ ; { prepare for show_info if recursion is needed }
    case  $math\_type(p)$  of
      math_char: begin print_ln; print_current_string; print_fam_and_char( $p$ );
      end;
      sub_box: show_info; { recursive call }
      sub_mlist: if info( $p$ ) = null then
        begin print_ln; print_current_string; print("{}");
        end
      else show_info; { recursive call }
    othercases do_nothing { empty }
  endcases;
  flush_char; { remove  $c$  from the recursion history }
end;
end;

```

867. The inelegant introduction of *show_info* in the code above seems better than the alternative of using Pascal's strange *forward* declaration for a procedure with parameters. The Pascal convention about dropping parameters from a post-*forward* procedure is, frankly, so intolerable to the author of T_EX that he would rather stoop to communication via a global temporary variable. (A similar stupidity occurred with respect to *hlist_out* and *vlist_out* above, and it will occur with respect to *mlist_to_hlist* below.)

```

procedure show_info; { the reader will kindly forgive this }
  begin show_node_list(info(temp_ptr));
  end;

```

868. ⟨Declare procedures needed for displaying the elements of mlists 865⟩ +=

```

procedure print_style( $c$  : integer);
  begin case  $c \bmod 2$  of
    0: print_esc("displaystyle"); { display_style = 0 }
    1: print_esc("textstyle"); { text_style = 2 }
    2: print_esc("scriptstyle"); { script_style = 4 }
    3: print_esc("scriptscriptstyle"); { script_script_style = 6 }
  othercases print("Unknown□style!")
  endcases;
end;

```


869. \langle Display choice node p 869 $\rangle \equiv$

```

begin print_esc("mathchoice"); append_char("D"); show_node_list(display_mlist(p)); flush_char;
append_char("T"); show_node_list(text_mlist(p)); flush_char; append_char("S");
show_node_list(script_mlist(p)); flush_char; append_char("s"); show_node_list(script_script_mlist(p));
flush_char;
end

```

This code is used in section 864.

870. \langle Display normal noad p 870 $\rangle \equiv$

```

begin case type(p) of
ord_noad: print_esc("mathord");
op_noad: print_esc("mathop");
bin_noad: print_esc("mathbin");
rel_noad: print_esc("mathrel");
open_noad: print_esc("mathopen");
close_noad: print_esc("mathclose");
punct_noad: print_esc("mathpunct");
inner_noad: print_esc("mathinner");
over_noad: print_esc("overline");
under_noad: print_esc("underline");
vcenter_noad: print_esc("vcenter");
radical_noad: begin print_esc("radical"); print_delimiter(left_delimiter(p));
end;
accent_noad: begin print_esc("accent"); print_fam_and_char(accent_chr(p));
end;
left_noad: begin print_esc("left"); print_delimiter(delimiter(p));
end;
right_noad: begin if subtype(p) = normal then print_esc("right")
else print_esc("middle");
print_delimiter(delimiter(p));
end;
end;
if type(p) < left_noad then
begin if subtype(p)  $\neq$  normal then
if subtype(p) = limits then print_esc("limits")
else print_esc("nolimits");
print_subsidary_data(nucleus(p), ".");
end;
print_subsidary_data(supscr(p), "^"); print_subsidary_data(subscr(p), "_");
end

```

This code is used in section 864.

871. $\langle \text{Display fraction noad } p \text{ 871} \rangle \equiv$

```

begin print_esc("fraction",_thickness_);
if thickness(p) = default_code then print("=_default")
else print_scaled(thickness(p));
if (small_fam(left_delimiter(p))  $\neq$  0)  $\vee$  (small_char(left_delimiter(p))  $\neq$  min_quarterword)  $\vee$ 
    (large_fam(left_delimiter(p))  $\neq$  0)  $\vee$  (large_char(left_delimiter(p))  $\neq$  min_quarterword) then
begin print(",_left-delimiter_"); print_delimiter(left_delimiter(p));
end;
if (small_fam(right_delimiter(p))  $\neq$  0)  $\vee$  (small_char(right_delimiter(p))  $\neq$  min_quarterword)  $\vee$ 
    (large_fam(right_delimiter(p))  $\neq$  0)  $\vee$  (large_char(right_delimiter(p))  $\neq$  min_quarterword) then
begin print(",_right-delimiter_"); print_delimiter(right_delimiter(p));
end;
print_subsidary_data(numerator(p), "\"); print_subsidary_data(denominator(p), "/");
end

```

This code is used in section 864.

872. That which can be displayed can also be destroyed.

$\langle \text{Cases of } \text{flush_node_list} \text{ that arise in mlists only 872} \rangle \equiv$

```

style_node: begin free_node(p, style_node_size); goto done;
end;
choice_node: begin flush_node_list(display_mlist(p)); flush_node_list(text_mlist(p));
    flush_node_list(script_mlist(p)); flush_node_list(script_script_mlist(p)); free_node(p, style_node_size);
goto done;
end;
ord_noad, op_noad, bin_noad, rel_noad, open_noad, close_noad, punct_noad, inner_noad, radical_noad,
    over_noad, under_noad, vcenter_noad, accent_noad:
begin if math_type(nucleus(p))  $\geq$  sub_box then flush_node_list(info(nucleus(p)));
if math_type(supscr(p))  $\geq$  sub_box then flush_node_list(info(supscr(p)));
if math_type(subscr(p))  $\geq$  sub_box then flush_node_list(info(subscr(p)));
if type(p) = radical_noad then free_node(p, radical_noad_size)
else if type(p) = accent_noad then free_node(p, accent_noad_size)
    else free_node(p, noad_size);
goto done;
end;
left_noad, right_noad: begin free_node(p, noad_size); goto done;
end;
fraction_noad: begin flush_node_list(info(numerator(p))); flush_node_list(info(denominator(p)));
    free_node(p, fraction_noad_size); goto done;
end;

```

This code is used in section 220.

873. Subroutines for math mode. In order to convert mlists to hlists, i.e., noads to nodes, we need several subroutines that are conveniently dealt with now.

Let us first introduce the macros that make it easy to get at the parameters and other font information. A size code, which is a multiple of 16, is added to a family number to get an index into the table of internal font numbers for each combination of family and size. (Be alert: Size codes get larger as the type gets smaller.)

```

define text_size = 0 { size code for the largest size in a family }
define script_size = 16 { size code for the medium size in a family }
define script_script_size = 32 { size code for the smallest size in a family }

⟨Basic printing procedures 57⟩ +=
procedure print_size(s : integer);
  begin if s = text_size then print_esc("textfont")
  else if s = script_size then print_esc("scriptfont")
    else print_esc("scriptscriptfont");
  end;

```

874. Before an mlist is converted to an hlist, TeX makes sure that the fonts in family 2 have enough parameters to be math-symbol fonts, and that the fonts in family 3 have enough parameters to be math-extension fonts. The math-symbol parameters are referred to by using the following macros, which take a size code as their parameter; for example, *num1*(*cur_size*) gives the value of the *num1* parameter for the current size.

```

define mathsy_end(#) ≡ fam_fnt(2 + #) ] ].sc
define mathsy(#) ≡ font_info [ # + param_base [ mathsy_end
define math_x_height ≡ mathsy(5) { height of 'x' }
define math_quad ≡ mathsy(6) { 18mu }
define num1 ≡ mathsy(8) { numerator shift-up in display styles }
define num2 ≡ mathsy(9) { numerator shift-up in non-display, non-\atop }
define num3 ≡ mathsy(10) { numerator shift-up in non-display \atop }
define denom1 ≡ mathsy(11) { denominator shift-down in display styles }
define denom2 ≡ mathsy(12) { denominator shift-down in non-display styles }
define sup1 ≡ mathsy(13) { superscript shift-up in uncramped display style }
define sup2 ≡ mathsy(14) { superscript shift-up in uncramped non-display }
define sup3 ≡ mathsy(15) { superscript shift-up in cramped styles }
define sub1 ≡ mathsy(16) { subscript shift-down if superscript is absent }
define sub2 ≡ mathsy(17) { subscript shift-down if superscript is present }
define sup_drop ≡ mathsy(18) { superscript baseline below top of large box }
define sub_drop ≡ mathsy(19) { subscript baseline below bottom of large box }
define delim1 ≡ mathsy(20) { size of \atopwithdelims delimiters in display styles }
define delim2 ≡ mathsy(21) { size of \atopwithdelims delimiters in non-displays }
define axis_height ≡ mathsy(22) { height of fraction lines above the baseline }
define total_mathsy_params = 22

```

875. The math-extension parameters have similar macros, but the size code is omitted (since it is always *cur_size* when we refer to such parameters).

```

define mathex(#) ≡ font_info[# + param_base[fam_fnt(3 + cur_size)]].sc
define default_rule_thickness ≡ mathex(8) { thickness of \over bars }
define big_op_spacing1 ≡ mathex(9) { minimum clearance above a displayed op }
define big_op_spacing2 ≡ mathex(10) { minimum clearance below a displayed op }
define big_op_spacing3 ≡ mathex(11) { minimum baselineskip above displayed op }
define big_op_spacing4 ≡ mathex(12) { minimum baselineskip below displayed op }
define big_op_spacing5 ≡ mathex(13) { padding above and below displayed limits }
define total_mathex_params = 13

```

876. We also need to compute the change in style between mlists and their subsidiaries. The following macros define the subsidiary style for an overlined nucleus (*cramped_style*), for a subscript or a superscript (*sub_style* or *sup_style*), or for a numerator or denominator (*num_style* or *denom_style*).

```

define cramped_style(#)  $\equiv 2 * (\# \text{ div } 2) + \textit{cramped}$  {cramp the style}
define sub_style(#)  $\equiv 2 * (\# \text{ div } 4) + \textit{script\_style} + \textit{cramped}$  {smaller and cramped}
define sup_style(#)  $\equiv 2 * (\# \text{ div } 4) + \textit{script\_style} + (\# \text{ mod } 2)$  {smaller}
define num_style(#)  $\equiv \# + 2 - 2 * (\# \text{ div } 6)$  {smaller unless already script-script}
define denom_style(#)  $\equiv 2 * (\# \text{ div } 2) + \textit{cramped} + 2 - 2 * (\# \text{ div } 6)$  {smaller, cramped}

```

877. When the style changes, the following piece of program computes associated information:

(Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877) \equiv

```

begin if cur_style < script_style then cur_size  $\leftarrow$  text_size
else cur_size  $\leftarrow 16 * ((\textit{cur\_style} - \textit{text\_style}) \text{ div } 2)$ ;
cur_mu  $\leftarrow x\_over\_n(\textit{math\_quad}(\textit{cur\_size}), 18)$ ;
end

```

This code is used in sections 894, 900, 901, 904, 928, 934, 936, and 937.

878. Here is a function that returns a pointer to a rule node having a given thickness *t*. The rule will extend horizontally to the boundary of the vlist that eventually contains it.

```

function fraction_rule(t : scaled): pointer; {construct the bar for a fraction}
  var p: pointer; {the new node}
  begin p  $\leftarrow$  new_rule; height(p)  $\leftarrow$  t; depth(p)  $\leftarrow$  0; fraction_rule  $\leftarrow$  p;
  end;

```

879. The *overbar* function returns a pointer to a vlist box that consists of a given box *b*, above which has been placed a kern of height *k* under a fraction rule of thickness *t* under additional space of height *t*.

```

function overbar(b : pointer; k, t : scaled): pointer;
  var p, q: pointer; {nodes being constructed}
  begin p  $\leftarrow$  new_kern(k); link(p)  $\leftarrow$  b; q  $\leftarrow$  fraction_rule(t); link(q)  $\leftarrow$  p; p  $\leftarrow$  new_kern(t); link(p)  $\leftarrow$  q;
  overbar  $\leftarrow$  vpack(p, natural);
  end;

```

880. The *var_delimiter* function, which finds or constructs a sufficiently large delimiter, is the most interesting of the auxiliary functions that currently concern us. Given a pointer d to a delimiter field in some noad, together with a size code s and a vertical distance v , this function returns a pointer to a box that contains the smallest variant of d whose height plus depth is v or more. (And if no variant is large enough, it returns the largest available variant.) In particular, this routine will construct arbitrarily large delimiters from extensible components, if d leads to such characters.

The value returned is a box whose *shift_amount* has been set so that the box is vertically centered with respect to the axis in the given size. If a built-up symbol is returned, the height of the box before shifting will be the height of its topmost component.

⟨Declare subprocedures for *var_delimiter* 883⟩

```
function var_delimiter( $d$  : pointer;  $s$  : small_number;  $v$  : scaled): pointer;
  label found, continue;
  var  $b$ : pointer; { the box that will be constructed }
       $f, g$ : internal_font_number; { best-so-far and tentative font codes }
       $c, x, y$ : quarterword; { best-so-far and tentative character codes }
       $m, n$ : integer; { the number of extensible pieces }
       $u$ : scaled; { height-plus-depth of a tentative character }
       $w$ : scaled; { largest height-plus-depth so far }
       $q$ : four_quarters; { character info }
       $hd$ : eight_bits; { height-depth byte }
       $r$ : four_quarters; { extensible pieces }
       $z$ : small_number; { runs through font family members }
      large_attempt: boolean; { are we trying the “large” variant? }
  begin  $f \leftarrow null\_font$ ;  $w \leftarrow 0$ ; large_attempt  $\leftarrow$  false;  $z \leftarrow small\_fam(d)$ ;  $x \leftarrow small\_char(d)$ ;
  loop begin ⟨Look at the variants of ( $z, x$ ); set  $f$  and  $c$  whenever a better character is found; goto
    found as soon as a large enough variant is encountered 881);
    if large_attempt then goto found; { there were none large enough }
    large_attempt  $\leftarrow$  true;  $z \leftarrow large\_fam(d)$ ;  $x \leftarrow large\_char(d)$ ;
  end;
found: if  $f \neq null\_font$  then ⟨Make variable  $b$  point to a box for ( $f, c$ ) 884⟩
  else begin  $b \leftarrow new\_null\_box$ ; width( $b$ )  $\leftarrow null\_delimiter\_space$ ;
    { use this width if no delimiter was found }
  end;
  shift_amount( $b$ )  $\leftarrow half(height(b) - depth(b)) - axis\_height(s)$ ; var_delimiter  $\leftarrow b$ ;
end;
```

881. The search process is complicated slightly by the facts that some of the characters might not be present in some of the fonts, and they might not be probed in increasing order of height.

```
⟨Look at the variants of ( $z, x$ ); set  $f$  and  $c$  whenever a better character is found; goto found as soon as a
  large enough variant is encountered 881⟩  $\equiv$ 
if ( $z \neq 0$ )  $\vee$  ( $x \neq min\_quarterword$ ) then
  begin  $z \leftarrow z + s + 16$ ;
  repeat  $z \leftarrow z - 16$ ;  $g \leftarrow fam\_fnt(z)$ ;
    if  $g \neq null\_font$  then ⟨Look at the list of characters starting with  $x$  in font  $g$ ; set  $f$  and  $c$  whenever
      a better character is found; goto found as soon as a large enough variant is encountered 882);
  until  $z < 16$ ;
end
```

This code is used in section 880.

882. \langle Look at the list of characters starting with x in font g ; set f and c whenever a better character is found; **goto** *found* as soon as a large enough variant is encountered 882 $\rangle \equiv$

```

begin  $y \leftarrow x$ ;
if  $(qo(y) \geq font\_bc[g]) \wedge (qo(y) \leq font\_ec[g])$  then
  begin continue:  $q \leftarrow char\_info(g)(y)$ ;
  if char_exists( $q$ ) then
    begin if char_tag( $q$ ) = ext_tag then
      begin  $f \leftarrow g$ ;  $c \leftarrow y$ ; goto found;
    end;
     $hd \leftarrow height\_depth(q)$ ;  $u \leftarrow char\_height(g)(hd) + char\_depth(g)(hd)$ ;
    if  $u > w$  then
      begin  $f \leftarrow g$ ;  $c \leftarrow y$ ;  $w \leftarrow u$ ;
      if  $u \geq v$  then goto found;
    end;
    if char_tag( $q$ ) = list_tag then
      begin  $y \leftarrow rem\_byte(q)$ ; goto continue;
    end;
  end;
end;
end

```

This code is used in section 881.

883. Here is a subroutine that creates a new box, whose list contains a single character, and whose width includes the italic correction for that character. The height or depth of the box will be negative, if the height or depth of the character is negative; thus, this routine may deliver a slightly different result than *hpack* would produce.

\langle Declare subprocedures for *var_delimiter* 883 $\rangle \equiv$

```

function char_box( $f : internal\_font\_number$ ;  $c : quarterword$ ): pointer;
  var  $q$ : four-quarters;  $hd$ : eight-bits; { height-depth byte }
   $b, p$ : pointer; { the new box and its character node }
  begin  $q \leftarrow char\_info(f)(c)$ ;  $hd \leftarrow height\_depth(q)$ ;  $b \leftarrow new\_null\_box$ ;
   $width(b) \leftarrow char\_width(f)(q) + char\_italic(f)(q)$ ;  $height(b) \leftarrow char\_height(f)(hd)$ ;
   $depth(b) \leftarrow char\_depth(f)(hd)$ ;  $p \leftarrow get\_avail$ ;  $character(p) \leftarrow c$ ;  $font(p) \leftarrow f$ ;  $list\_ptr(b) \leftarrow p$ ;
  char_box  $\leftarrow b$ ;
  end;

```

See also sections 885 and 886.

This code is used in section 880.

884. When the following code is executed, *char_tag*(q) will be equal to *ext_tag* if and only if a built-up symbol is supposed to be returned.

\langle Make variable b point to a box for (f, c) 884 $\rangle \equiv$

```

if char_tag( $q$ ) = ext_tag then
   $\langle$  Construct an extensible character in a new box  $b$ , using recipe rem_byte( $q$ ) and font  $f$  887  $\rangle$ 
else  $b \leftarrow char\_box(f, c)$ 

```

This code is used in section 880.

885. When we build an extensible character, it's handy to have the following subroutine, which puts a given character on top of the characters already in box b :

```

⟨ Declare subprocedures for var_delimiter 883 ⟩ +≡
procedure stack_into_box( $b$  : pointer;  $f$  : internal_font_number;  $c$  : quarterword);
  var  $p$  : pointer; { new node placed into  $b$  }
  begin  $p \leftarrow \text{char\_box}(f, c)$ ;  $\text{link}(p) \leftarrow \text{list\_ptr}(b)$ ;  $\text{list\_ptr}(b) \leftarrow p$ ;  $\text{height}(b) \leftarrow \text{height}(p)$ ;
  end;

```

886. Another handy subroutine computes the height plus depth of a given character:

```

⟨ Declare subprocedures for var_delimiter 883 ⟩ +≡
function height_plus_depth( $f$  : internal_font_number;  $c$  : quarterword): scaled;
  var  $q$  : four_quarters;  $hd$  : eight_bits; { height_depth byte }
  begin  $q \leftarrow \text{char\_info}(f)(c)$ ;  $hd \leftarrow \text{height\_depth}(q)$ ;
  height_plus_depth  $\leftarrow \text{char\_height}(f)(hd) + \text{char\_depth}(f)(hd)$ ;
  end;

```

887. ⟨ Construct an extensible character in a new box b , using recipe *rem_byte*(q) and font f 887 ⟩ \equiv

```

begin  $b \leftarrow \text{new\_null\_box}$ ;  $\text{type}(b) \leftarrow \text{vlist\_node}$ ;  $r \leftarrow \text{font\_info}[\text{exten\_base}[f] + \text{rem\_byte}(q)].\text{qqqq}$ ;
  ⟨ Compute the minimum suitable height,  $w$ , and the corresponding number of extension steps,  $n$ ; also set
    width( $b$ ) 888 ⟩;
   $c \leftarrow \text{ext\_bot}(r)$ ;
  if  $c \neq \text{min\_quarterword}$  then stack_into_box( $b, f, c$ );
   $c \leftarrow \text{ext\_rep}(r)$ ;
  for  $m \leftarrow 1$  to  $n$  do stack_into_box( $b, f, c$ );
   $c \leftarrow \text{ext\_mid}(r)$ ;
  if  $c \neq \text{min\_quarterword}$  then
    begin stack_into_box( $b, f, c$ );  $c \leftarrow \text{ext\_rep}(r)$ ;
    for  $m \leftarrow 1$  to  $n$  do stack_into_box( $b, f, c$ );
    end;
   $c \leftarrow \text{ext\_top}(r)$ ;
  if  $c \neq \text{min\_quarterword}$  then stack_into_box( $b, f, c$ );
  depth( $b$ )  $\leftarrow w - \text{height}(b)$ ;
end

```

This code is used in section 884.

888. The width of an extensible character is the width of the repeatable module. If this module does not have positive height plus depth, we don't use any copies of it, otherwise we use as few as possible (in groups of two if there is a middle part).

```

⟨ Compute the minimum suitable height,  $w$ , and the corresponding number of extension steps,  $n$ ; also set
 $width(b)$  888 ⟩  $\equiv$ 
 $c \leftarrow ext\_rep(r)$ ;  $u \leftarrow height\_plus\_depth(f, c)$ ;  $w \leftarrow 0$ ;  $q \leftarrow char\_info(f)(c)$ ;
 $width(b) \leftarrow char\_width(f)(q) + char\_italic(f)(q)$ ;
 $c \leftarrow ext\_bot(r)$ ; if  $c \neq min\_quarterword$  then  $w \leftarrow w + height\_plus\_depth(f, c)$ ;
 $c \leftarrow ext\_mid(r)$ ; if  $c \neq min\_quarterword$  then  $w \leftarrow w + height\_plus\_depth(f, c)$ ;
 $c \leftarrow ext\_top(r)$ ; if  $c \neq min\_quarterword$  then  $w \leftarrow w + height\_plus\_depth(f, c)$ ;
 $n \leftarrow 0$ ;
if  $u > 0$  then
  while  $w < v$  do
    begin  $w \leftarrow w + u$ ;  $incr(n)$ ;
    if  $ext\_mid(r) \neq min\_quarterword$  then  $w \leftarrow w + u$ ;
  end

```

This code is used in section 887.

889. The next subroutine is much simpler; it is used for numerators and denominators of fractions as well as for displayed operators and their limits above and below. It takes a given box b and changes it so that the new box is centered in a box of width w . The centering is done by putting `\hss` glue at the left and right of the list inside b , then packaging the new box; thus, the actual box might not really be centered, if it already contains infinite glue.

The given box might contain a single character whose italic correction has been added to the width of the box; in this case a compensating kern is inserted.

```

function  $rebox(b : pointer; w : scaled) : pointer$ ;
var  $p : pointer$ ; { temporary register for list manipulation }
 $f : internal\_font\_number$ ; { font in a one-character box }
 $v : scaled$ ; { width of a character without italic correction }
begin if  $(width(b) \neq w) \wedge (list\_ptr(b) \neq null)$  then
  begin if  $type(b) = vlist\_node$  then  $b \leftarrow hpack(b, natural)$ ;
   $p \leftarrow list\_ptr(b)$ ;
  if  $(is\_char\_node(p)) \wedge (link(p) = null)$  then
    begin  $f \leftarrow font(p)$ ;  $v \leftarrow char\_width(f)(char\_info(f)(character(p)))$ ;
    if  $v \neq width(b)$  then  $link(p) \leftarrow new\_kern(width(b) - v)$ ;
    end;
   $free\_node(b, box\_node\_size)$ ;  $b \leftarrow new\_glue(ss\_glue)$ ;  $link(b) \leftarrow p$ ;
  while  $link(p) \neq null$  do  $p \leftarrow link(p)$ ;
   $link(p) \leftarrow new\_glue(ss\_glue)$ ;  $rebox \leftarrow hpack(b, w, exactly)$ ;
  end
else begin  $width(b) \leftarrow w$ ;  $rebox \leftarrow b$ ;
  end;
end;

```


890. Here is a subroutine that creates a new glue specification from another one that is expressed in ‘mu’, given the value of the math unit.

```

define mu_mult(#)  $\equiv$  nx_plus_y(n, #, xn_over_d(#, f, '200000'))
function math_glue(g : pointer; m : scaled): pointer;
  var p: pointer; { the new glue specification }
    n: integer; { integer part of m }
    f: scaled; { fraction part of m }
  begin n  $\leftarrow$  x_over_n(m, '200000'); f  $\leftarrow$  remainder;
  if f < 0 then
    begin decr(n); f  $\leftarrow$  f + '200000';
    end;
  p  $\leftarrow$  get_node(glue_spec_size); width(p)  $\leftarrow$  mu_mult(width(g)); { convert mu to pt }
  stretch_order(p)  $\leftarrow$  stretch_order(g);
  if stretch_order(p) = normal then stretch(p)  $\leftarrow$  mu_mult(stretch(g))
  else stretch(p)  $\leftarrow$  stretch(g);
  shrink_order(p)  $\leftarrow$  shrink_order(g);
  if shrink_order(p) = normal then shrink(p)  $\leftarrow$  mu_mult(shrink(g))
  else shrink(p)  $\leftarrow$  shrink(g);
  math_glue  $\leftarrow$  p;
end;

```

891. The *math_kern* subroutine removes *mu_glue* from a kern node, given the value of the math unit.

```

procedure math_kern(p : pointer; m : scaled);
  var n: integer; { integer part of m }
    f: scaled; { fraction part of m }
  begin if subtype(p) = mu_glue then
    begin n  $\leftarrow$  x_over_n(m, '200000'); f  $\leftarrow$  remainder;
    if f < 0 then
      begin decr(n); f  $\leftarrow$  f + '200000';
      end;
    width(p)  $\leftarrow$  mu_mult(width(p)); subtype(p)  $\leftarrow$  explicit;
    end;
  end;

```

892. Sometimes it is necessary to destroy an mlist. The following subroutine empties the current list, assuming that *abs(mode)* = *mmode*.

```

procedure flush_math;
  begin flush_node_list(link(head)); flush_node_list(incompleat_noad); link(head)  $\leftarrow$  null; tail  $\leftarrow$  head;
  incompleat_noad  $\leftarrow$  null;
end;

```

893. Typesetting math formulas. TeX's most important routine for dealing with formulas is called *mlist_to_hlist*. After a formula has been scanned and represented as an mlist, this routine converts it to an hlist that can be placed into a box or incorporated into the text of a paragraph. There are three implicit parameters, passed in global variables: *cur_mlist* points to the first node or noad in the given mlist (and it might be *null*); *cur_style* is a style code; and *mlist_penalties* is *true* if penalty nodes for potential line breaks are to be inserted into the resulting hlist. After *mlist_to_hlist* has acted, *link(temp_head)* points to the translated hlist.

Since mlists can be inside mlists, the procedure is recursive. And since this is not part of TeX's inner loop, the program has been written in a manner that stresses compactness over efficiency.

```

⟨Global variables 13⟩ +≡
cur_mlist: pointer; {beginning of mlist to be translated}
cur_style: small_number; {style code at current place in the list}
cur_size: small_number; {size code corresponding to cur_style}
cur_mu: scaled; {the math unit width corresponding to cur_size}
mlist_penalties: boolean; {should mlist_to_hlist insert penalties?}

```

894. The recursion in *mlist_to_hlist* is due primarily to a subroutine called *clean_box* that puts a given noad field into a box using a given math style; *mlist_to_hlist* can call *clean_box*, which can call *mlist_to_hlist*.

The box returned by *clean_box* is “clean” in the sense that its *shift_amount* is zero.

```

procedure mlist_to_hlist; forward;
function clean_box(p: pointer; s: small_number): pointer;
  label found;
  var q: pointer; {beginning of a list to be boxed}
      save_style: small_number; {cur_style to be restored}
      x: pointer; {box to be returned}
      r: pointer; {temporary pointer}
  begin case math_type(p) of
    math_char: begin cur_mlist  $\leftarrow$  new_noad; mem[nucleus(cur_mlist)]  $\leftarrow$  mem[p];
      end;
    sub_box: begin q  $\leftarrow$  info(p); goto found;
      end;
    sub_mlist: cur_mlist  $\leftarrow$  info(p);
  othercases begin q  $\leftarrow$  new_null_box; goto found;
    end
  endcases;
  save_style  $\leftarrow$  cur_style; cur_style  $\leftarrow$  s; mlist_penalties  $\leftarrow$  false;
  mlist_to_hlist; q  $\leftarrow$  link(temp_head); {recursive call}
  cur_style  $\leftarrow$  save_style; {restore the style}
  ⟨Set up the values of cur_size and cur_mu, based on cur_style 877⟩;
found: if is_char_node(q)  $\vee$  (q = null) then x  $\leftarrow$  hpack(q, natural)
else if (link(q) = null)  $\wedge$  (type(q)  $\leq$  vlist_node)  $\wedge$  (shift_amount(q) = 0) then x  $\leftarrow$  q
    {it's already clean}
  else x  $\leftarrow$  hpack(q, natural);
  ⟨Simplify a trivial box 895⟩;
  clean_box  $\leftarrow$  x;
end;

```

895. Here we save memory space in a common case.

```

⟨Simplify a trivial box 895⟩ ≡
  q ← list_ptr(x);
  if is_char_node(q) then
    begin r ← link(q);
    if r ≠ null then
      if link(r) = null then
        if ¬is_char_node(r) then
          if type(r) = kern_node then { unneeded italic correction }
            begin free_node(r, small_node_size); link(q) ← null;
            end;
        end;
      end
end

```

This code is used in section 894.

896. It is convenient to have a procedure that converts a *math_char* field to an “unpacked” form. The *fetch* routine sets *cur_f*, *cur_c*, and *cur_i* to the font code, character code, and character information bytes of a given noad field. It also takes care of issuing error messages for nonexistent characters; in such cases, *char_exists(cur_i)* will be *false* after *fetch* has acted, and the field will also have been reset to *empty*.

```

procedure fetch(a : pointer); { unpack the math_char field a }
begin cur_c ← character(a); cur_f ← fam_fnt(fam(a) + cur_size);
if cur_f = null_font then ⟨Complain about an undefined family and set cur_i null 897⟩
else begin if (qo(cur_c) ≥ font_bc[cur_f]) ∧ (qo(cur_c) ≤ font_ec[cur_f]) then
  cur_i ← char_info(cur_f)(cur_c)
else cur_i ← null_character;
if ¬(char_exists(cur_i)) then
  begin char_warning(cur_f, qo(cur_c)); math_type(a) ← empty; cur_i ← null_character;
  end;
end;
end;

```

```

897. ⟨Complain about an undefined family and set cur_i null 897⟩ ≡
begin print_err(""); print_size(cur_size); print_char(" "); print_int(fam(a));
print(" is undefined (character "); print_ASCII(qo(cur_c)); print_char(")");
help4("Somewhere in the math formula just ended, you used the")
("stated character from an undefined font family. For example,")
("plain TeX doesn't allow \it or \sl in subscripts. Proceed,")
("and I'll try to forget that I needed that character."); error; cur_i ← null_character;
math_type(a) ← empty;
end

```

This code is used in section 896.

898. The outputs of *fetch* are placed in global variables.

```

⟨Global variables 13⟩ +≡
cur_f: internal_font_number; { the font field of a math_char }
cur_c: quarterword; { the character field of a math_char }
cur_i: four_quarters; { the char_info of a math_char, or a lig/kern instruction }

```

899. We need to do a lot of different things, so *mlist_to_hlist* makes two passes over the given mlist.

The first pass does most of the processing: It removes “mu” spacing from glue, it recursively evaluates all subsidiary mlists so that only the top-level mlist remains to be handled, it puts fractions and square roots and such things into boxes, it attaches subscripts and superscripts, and it computes the overall height and depth of the top-level mlist so that the size of delimiters for a *left_noad* and a *right_noad* will be known. The hlist resulting from each noad is recorded in that noad’s *new_hlist* field, an integer field that replaces the *nucleus* or *thickness*.

The second pass eliminates all noads and inserts the correct glue and penalties between nodes.

define *new_hlist*(#) \equiv *mem*[*nucleus*(#)].*int* { the translation of an mlist }

900. Here is the overall plan of *mlist_to_hlist*, and the list of its local variables.

define *done_with_noad* = 80 { go here when a noad has been fully translated }

define *done_with_node* = 81 { go here when a node has been fully converted }

define *check_dimensions* = 82 { go here to update *max_h* and *max_d* }

define *delete_q* = 83 { go here to delete *q* and move to the next node }

⟨ Declare math construction procedures 908 ⟩

procedure *mlist_to_hlist*;

label *reswitch*, *check_dimensions*, *done_with_noad*, *done_with_node*, *delete_q*, *done*;

var *mlist*: *pointer*; { beginning of the given list }

penalties: *boolean*; { should penalty nodes be inserted? }

style: *small_number*; { the given style }

save_style: *small_number*; { holds *cur_style* during recursion }

q: *pointer*; { runs through the mlist }

r: *pointer*; { the most recent noad preceding *q* }

r_type: *small_number*; { the *type* of noad *r*, or *op_noad* if *r* = *null* }

t: *small_number*; { the effective *type* of noad *q* during the second pass }

p, *x*, *y*, *z*: *pointer*; { temporary registers for list construction }

pen: *integer*; { a penalty to be inserted }

s: *small_number*; { the size of a noad to be deleted }

max_h, *max_d*: *scaled*; { maximum height and depth of the list translated so far }

delta: *scaled*; { offset between subscript and superscript }

begin *mlist* \leftarrow *cur_mlist*; *penalties* \leftarrow *mlist_penalties*; *style* \leftarrow *cur_style*;

{ tuck global parameters away as local variables }

q \leftarrow *mlist*; *r* \leftarrow *null*; *r_type* \leftarrow *op_noad*; *max_h* \leftarrow 0; *max_d* \leftarrow 0;

⟨ Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877 ⟩;

while *q* \neq *null* **do** ⟨ Process node-or-noad *q* as much as possible in preparation for the second pass of *mlist_to_hlist*, then move to the next item in the mlist 901 ⟩;

⟨ Convert a final *bin_noad* to an *ord_noad* 903 ⟩;

⟨ Make a second pass over the mlist, removing all noads and inserting the proper spacing and penalties 934 ⟩;

end;

901. We use the fact that no character nodes appear in an mlist, hence the field *type*(*q*) is always present.
 ⟨ Process node-or-noad *q* as much as possible in preparation for the second pass of *mlist_to_hlist*, then move to the next item in the mlist 901 ⟩ ≡
begin ⟨ Do first-pass processing based on *type*(*q*); **goto** *done_with_noad* if a noad has been fully processed, **goto** *check_dimensions* if it has been translated into *new_hlist*(*q*), or **goto** *done_with_node* if a node has been fully processed 902 ⟩;
check_dimensions: *z* ← *hpack*(*new_hlist*(*q*), *natural*);
if *height*(*z*) > *max_h* **then** *max_h* ← *height*(*z*);
if *depth*(*z*) > *max_d* **then** *max_d* ← *depth*(*z*);
free_node(*z*, *box_node_size*);
done_with_noad: *r* ← *q*; *r_type* ← *type*(*r*);
if *r_type* = *right_noad* **then**
begin *r_type* ← *left_noad*; *cur_style* ← *style*;
 ⟨ Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877 ⟩;
end;
done_with_node: *q* ← *link*(*q*);
end

This code is used in section 900.

902. One of the things we must do on the first pass is change a *bin_noad* to an *ord_noad* if the *bin_noad* is not in the context of a binary operator. The values of *r* and *r_type* make this fairly easy.
 ⟨ Do first-pass processing based on *type*(*q*); **goto** *done_with_noad* if a noad has been fully processed, **goto** *check_dimensions* if it has been translated into *new_hlist*(*q*), or **goto** *done_with_node* if a node has been fully processed 902 ⟩ ≡
reswitch: *delta* ← 0;
case *type*(*q*) **of**
bin_noad: **case** *r_type* **of**
bin_noad, *op_noad*, *rel_noad*, *open_noad*, *punct_noad*, *left_noad*: **begin** *type*(*q*) ← *ord_noad*;
goto *reswitch*;
end;
othercases *do_nothing*
endcases;
rel_noad, *close_noad*, *punct_noad*, *right_noad*: **begin**
 ⟨ Convert a final *bin_noad* to an *ord_noad* 903 ⟩;
if *type*(*q*) = *right_noad* **then** **goto** *done_with_noad*;
end;
 ⟨ Cases for noads that can follow a *bin_noad* 907 ⟩
 ⟨ Cases for nodes that can appear in an mlist, after which we **goto** *done_with_node* 904 ⟩
othercases *confusion*("mlist1")
endcases;
 ⟨ Convert *nucleus*(*q*) to an hlist and attach the sub/superscripts 928 ⟩

This code is used in section 901.

903. ⟨ Convert a final *bin_noad* to an *ord_noad* 903 ⟩ ≡
if *r_type* = *bin_noad* **then** *type*(*r*) ← *ord_noad*

This code is used in sections 900 and 902.

904. \langle Cases for nodes that can appear in an mlist, after which we **goto** *done_with_node* 904 $\rangle \equiv$
style_node: **begin** *cur_style* \leftarrow *subtype*(*q*);
 \langle Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877 \rangle ;
goto *done_with_node*;
end;
choice_node: \langle Change this node to a style node followed by the correct choice, then **goto**
done_with_node 905 \rangle ;
ins_node, *mark_node*, *adjust_node*, *whatsit_node*, *penalty_node*, *disc_node*: **goto** *done_with_node*;
rule_node: **begin if** *height*(*q*) > *max_h* **then** *max_h* \leftarrow *height*(*q*);
if *depth*(*q*) > *max_d* **then** *max_d* \leftarrow *depth*(*q*);
goto *done_with_node*;
end;
glue_node: **begin** \langle Convert math glue to ordinary glue 906 \rangle ;
goto *done_with_node*;
end;
kern_node: **begin** *math_kern*(*q*, *cur_mu*); **goto** *done_with_node*;
end;

This code is used in section 902.

905. define *choose_mlist*(#) \equiv
begin *p* \leftarrow #(*q*); #(*q*) \leftarrow *null*; **end**
 \langle Change this node to a style node followed by the correct choice, then **goto** *done_with_node* 905 $\rangle \equiv$
begin case *cur_style* **div** 2 **of**
0: *choose_mlist*(*display_mlist*); { *display_style* = 0 }
1: *choose_mlist*(*text_mlist*); { *text_style* = 2 }
2: *choose_mlist*(*script_mlist*); { *script_style* = 4 }
3: *choose_mlist*(*script_script_mlist*); { *script_script_style* = 6 }
end; { there are no other cases }
flush_node_list(*display_mlist*(*q*)); *flush_node_list*(*text_mlist*(*q*)); *flush_node_list*(*script_mlist*(*q*));
flush_node_list(*script_script_mlist*(*q*));
type(*q*) \leftarrow *style_node*; *subtype*(*q*) \leftarrow *cur_style*; *width*(*q*) \leftarrow 0; *depth*(*q*) \leftarrow 0;
if *p* \neq *null* **then**
begin *z* \leftarrow *link*(*q*); *link*(*q*) \leftarrow *p*;
while *link*(*p*) \neq *null* **do** *p* \leftarrow *link*(*p*);
link(*p*) \leftarrow *z*;
end;
goto *done_with_node*;
end

This code is used in section 904.

906. Conditional math glue (`\nonscript`) results in a *glue_node* pointing to *zero_glue*, with *subtype*(*q*) = *cond_math_glue*; in such a case the node following will be eliminated if it is a glue or kern node and if the current size is different from *text_size*. Unconditional math glue (`\muskip`) is converted to normal glue by multiplying the dimensions by *cur_mu*.

```

⟨Convert math glue to ordinary glue 906⟩ ≡
  if subtype(q) = mu_glue then
    begin x ← glue_ptr(q); y ← math_glue(x, cur_mu); delete_glue_ref(x); glue_ptr(q) ← y;
      subtype(q) ← normal;
    end
  else if (cur_size ≠ text_size) ∧ (subtype(q) = cond_math_glue) then
    begin p ← link(q);
      if p ≠ null then
        if (type(p) = glue_node) ∨ (type(p) = kern_node) then
          begin link(q) ← link(p); link(p) ← null; flush_node_list(p);
            end;
          end
    end

```

This code is used in section 904.

907. ⟨Cases for noads that can follow a *bin_noad* 907⟩ ≡

```

left_noad: goto done_with_noad;
fraction_noad: begin make_fraction(q); goto check_dimensions;
  end;
op_noad: begin delta ← make_op(q);
  if subtype(q) = limits then goto check_dimensions;
  end;
ord_noad: make_ord(q);
open_noad, inner_noad: do_nothing;
radical_noad: make_radical(q);
over_noad: make_over(q);
under_noad: make_under(q);
accent_noad: make_math_accent(q);
vcenter_noad: make_vcenter(q);

```

This code is used in section 902.

908. Most of the actual construction work of *mlist_to_hlist* is done by procedures with names like *make_fraction*, *make_radical*, etc. To illustrate the general setup of such procedures, let's begin with a couple of simple ones.

```

⟨Declare math construction procedures 908⟩ ≡
procedure make_over(q : pointer);
  begin info(nucleus(q)) ← overbar(clean_box(nucleus(q), cramped_style(cur_style)),
    3 * default_rule_thickness, default_rule_thickness); math_type(nucleus(q)) ← sub_box;
  end;

```

See also sections 909, 910, 911, 912, 917, 923, 926, 930, and 936.

This code is used in section 900.

909. \langle Declare math construction procedures 908 $\rangle + \equiv$

```
procedure make_under(q : pointer);
  var p, x, y: pointer; { temporary registers for box construction }
  delta: scaled; { overall height plus depth }
  begin x  $\leftarrow$  clean_box(nucleus(q), cur_style); p  $\leftarrow$  new_kern(3 * default_rule_thickness); link(x)  $\leftarrow$  p;
  link(p)  $\leftarrow$  fraction_rule(default_rule_thickness); y  $\leftarrow$  vpack(x, natural);
  delta  $\leftarrow$  height(y) + depth(y) + default_rule_thickness; height(y)  $\leftarrow$  height(x);
  depth(y)  $\leftarrow$  delta - height(y); info(nucleus(q))  $\leftarrow$  y; math_type(nucleus(q))  $\leftarrow$  sub_box;
end;
```

910. \langle Declare math construction procedures 908 $\rangle + \equiv$

```
procedure make_vcenter(q : pointer);
  var v: pointer; { the box that should be centered vertically }
  delta: scaled; { its height plus depth }
  begin v  $\leftarrow$  info(nucleus(q));
  if type(v)  $\neq$  vlist_node then confusion("vcenter");
  delta  $\leftarrow$  height(v) + depth(v); height(v)  $\leftarrow$  axis_height(cur_size) + half(delta);
  depth(v)  $\leftarrow$  delta - height(v);
end;
```

911. According to the rules in the DVI file specifications, we ensure alignment between a square root sign and the rule above its nucleus by assuming that the baseline of the square-root symbol is the same as the bottom of the rule. The height of the square-root symbol will be the thickness of the rule, and the depth of the square-root symbol should exceed or equal the height-plus-depth of the nucleus plus a certain minimum clearance *clr*. The symbol will be placed so that the actual clearance is *clr* plus half the excess.

\langle Declare math construction procedures 908 $\rangle + \equiv$

```
procedure make_radical(q : pointer);
  var x, y: pointer; { temporary registers for box construction }
  delta, clr: scaled; { dimensions involved in the calculation }
  begin x  $\leftarrow$  clean_box(nucleus(q), cramped_style(cur_style));
  if cur_style < text_style then { display style }
    clr  $\leftarrow$  default_rule_thickness + (abs(math_x_height(cur_size)) div 4)
  else begin clr  $\leftarrow$  default_rule_thickness; clr  $\leftarrow$  clr + (abs(clr) div 4);
  end;
  y  $\leftarrow$  var_delimiter(left_delimiter(q), cur_size, height(x) + depth(x) + clr + default_rule_thickness);
  delta  $\leftarrow$  depth(y) - (height(x) + depth(x) + clr);
  if delta > 0 then clr  $\leftarrow$  clr + half(delta); { increase the actual clearance }
  shift_amount(y)  $\leftarrow$  -(height(x) + clr); link(y)  $\leftarrow$  overbar(x, clr, height(y));
  info(nucleus(q))  $\leftarrow$  hpack(y, natural); math_type(nucleus(q))  $\leftarrow$  sub_box;
end;
```


912. Slants are not considered when placing accents in math mode. The accenter is centered over the accentee, and the accent width is treated as zero with respect to the size of the final box.

⟨Declare math construction procedures 908⟩ +≡

```
procedure make_math_accent(q : pointer);
  label done, done1;
  var p, x, y: pointer; { temporary registers for box construction }
    a: integer; { address of lig/kern instruction }
    c: quarterword; { accent character }
    f: internal_font_number; { its font }
    i: four_quarters; { its char_info }
    s: scaled; { amount to skew the accent to the right }
    h: scaled; { height of character being accented }
    delta: scaled; { space to remove between accent and accentee }
    w: scaled; { width of the accentee, not including sub/superscripts }
  begin fetch(accent_chr(q));
  if char_exists(cur_i) then
    begin i ← cur_i; c ← cur_c; f ← cur_f;
    ⟨Compute the amount of skew 915⟩;
    x ← clean_box(nucleus(q), cramped_style(cur_style)); w ← width(x); h ← height(x);
    ⟨Switch to a larger accent if available and appropriate 914⟩;
    if h < x_height(f) then delta ← h else delta ← x_height(f);
    if (math_type(supscr(q)) ≠ empty) ∨ (math_type(subscr(q)) ≠ empty) then
      if math_type(nucleus(q)) = math_char then ⟨Swap the subscript and superscript into box x 916⟩;
      y ← char_box(f, c); shift_amount(y) ← s + half(w − width(y)); width(y) ← 0; p ← new_kern(−delta);
      link(p) ← x; link(y) ← p; y ← vpack(y, natural); width(y) ← width(x);
      if height(y) < h then ⟨Make the height of box y equal to h 913⟩;
      info(nucleus(q)) ← y; math_type(nucleus(q)) ← sub_box;
    end;
  end;
```

913. ⟨Make the height of box *y* equal to *h* 913⟩ ≡

```
begin p ← new_kern(h − height(y)); link(p) ← list_ptr(y); list_ptr(y) ← p; height(y) ← h;
end
```

This code is used in section 912.

914. ⟨Switch to a larger accent if available and appropriate 914⟩ ≡

```
loop begin if char_tag(i) ≠ list_tag then goto done;
  y ← rem_byte(i); i ← char_info(f)(y);
  if ¬char_exists(i) then goto done;
  if char_width(f)(i) > w then goto done;
  c ← y;
end;
```

done:

This code is used in section 912.

915. \langle Compute the amount of skew 915 $\rangle \equiv$

```

s ← 0;
if math_type(nucleus(q)) = math_char then
  begin fetch(nucleus(q));
  if char_tag(cur_i) = lig_tag then
    begin a ← lig_kern_start(cur_f)(cur_i); cur_i ← font_info[a].qqqq;
    if skip_byte(cur_i) > stop_flag then
      begin a ← lig_kern_restart(cur_f)(cur_i); cur_i ← font_info[a].qqqq;
      end;
    loop begin if qo(next_char(cur_i)) = skew_char[cur_f] then
      begin if op_byte(cur_i) ≥ kern_flag then
        if skip_byte(cur_i) ≤ stop_flag then s ← char_kern(cur_f)(cur_i);
        goto done1;
      end;
      if skip_byte(cur_i) ≥ stop_flag then goto done1;
      a ← a + qo(skip_byte(cur_i)) + 1; cur_i ← font_info[a].qqqq;
      end;
    end;
  end;
done1:

```

This code is used in section 912.

916. \langle Swap the subscript and superscript into box *x* 916 $\rangle \equiv$

```

begin flush_node_list(x); x ← new_noad; mem[nucleus(x)] ← mem[nucleus(q)];
mem[supscr(x)] ← mem[supscr(q)]; mem[subscr(x)] ← mem[subscr(q)];
mem[supscr(q)].hh ← empty_field; mem[subscr(q)].hh ← empty_field;
 $\mathit{math\_type}(\mathit{nucleus}(q)) \leftarrow \mathit{sub\_mlist}$ ;  $\mathit{info}(\mathit{nucleus}(q)) \leftarrow x$ ;  $x \leftarrow \mathit{clean\_box}(\mathit{nucleus}(q), \mathit{cur\_style})$ ;
 $\mathit{delta} \leftarrow \mathit{delta} + \mathit{height}(x) - h$ ;  $h \leftarrow \mathit{height}(x)$ ;
end

```

This code is used in section 912.

917. The *make_fraction* procedure is a bit different because it sets *new_hlist*(*q*) directly rather than making a sub-box.

\langle Declare math construction procedures 908 $\rangle + \equiv$

```

procedure make_fraction(q : pointer);
  var p, v, x, y, z: pointer; { temporary registers for box construction }
  delta, delta1, delta2, shift_up, shift_down, clr: scaled; { dimensions for box calculations }
  begin if thickness(q) = default_code then thickness(q) ← default_rule_thickness;
   $\langle$  Create equal-width boxes x and z for the numerator and denominator, and compute the default amounts
    shift_up and shift_down by which they are displaced from the baseline 918  $\rangle$ ;
  if thickness(q) = 0 then  $\langle$  Adjust shift_up and shift_down for the case of no fraction line 919  $\rangle$ 
  else  $\langle$  Adjust shift_up and shift_down for the case of a fraction line 920  $\rangle$ ;
   $\langle$  Construct a vlist box for the fraction, according to shift_up and shift_down 921  $\rangle$ ;
   $\langle$  Put the fraction into a box with its delimiters, and make new_hlist(q) point to it 922  $\rangle$ ;
  end;

```

918. \langle Create equal-width boxes x and z for the numerator and denominator, and compute the default amounts $shift_up$ and $shift_down$ by which they are displaced from the baseline 918 $\rangle \equiv$

```

 $x \leftarrow clean\_box(numerator(q), num\_style(cur\_style));$ 
 $z \leftarrow clean\_box(denominator(q), denom\_style(cur\_style));$ 
if  $width(x) < width(z)$  then  $x \leftarrow rebox(x, width(z))$ 
else  $z \leftarrow rebox(z, width(x))$ ;
if  $cur\_style < text\_style$  then { display style }
  begin  $shift\_up \leftarrow num1(cur\_size)$ ;  $shift\_down \leftarrow denom1(cur\_size)$ ;
  end
else begin  $shift\_down \leftarrow denom2(cur\_size)$ ;
  if  $thickness(q) \neq 0$  then  $shift\_up \leftarrow num2(cur\_size)$ 
  else  $shift\_up \leftarrow num3(cur\_size)$ ;
  end

```

This code is used in section 917.

919. The numerator and denominator must be separated by a certain minimum clearance, called clr in the following program. The difference between clr and the actual clearance is twice $delta$.

\langle Adjust $shift_up$ and $shift_down$ for the case of no fraction line 919 $\rangle \equiv$

```

begin if  $cur\_style < text\_style$  then  $clr \leftarrow 7 * default\_rule\_thickness$ 
else  $clr \leftarrow 3 * default\_rule\_thickness$ ;
 $delta \leftarrow half(clr - ((shift\_up - depth(x)) - (height(z) - shift\_down)))$ ;
if  $delta > 0$  then
  begin  $shift\_up \leftarrow shift\_up + delta$ ;  $shift\_down \leftarrow shift\_down + delta$ ;
  end;
end

```

This code is used in section 917.

920. In the case of a fraction line, the minimum clearance depends on the actual thickness of the line.

\langle Adjust $shift_up$ and $shift_down$ for the case of a fraction line 920 $\rangle \equiv$

```

begin if  $cur\_style < text\_style$  then  $clr \leftarrow 3 * thickness(q)$ 
else  $clr \leftarrow thickness(q)$ ;
 $delta \leftarrow half(thickness(q))$ ;  $delta1 \leftarrow clr - ((shift\_up - depth(x)) - (axis\_height(cur\_size) + delta))$ ;
 $delta2 \leftarrow clr - ((axis\_height(cur\_size) - delta) - (height(z) - shift\_down))$ ;
if  $delta1 > 0$  then  $shift\_up \leftarrow shift\_up + delta1$ ;
if  $delta2 > 0$  then  $shift\_down \leftarrow shift\_down + delta2$ ;
end

```

This code is used in section 917.

921. \langle Construct a vlist box for the fraction, according to $shift_up$ and $shift_down$ 921 $\rangle \equiv$

```

 $v \leftarrow new\_null\_box$ ;  $type(v) \leftarrow vlist\_node$ ;  $height(v) \leftarrow shift\_up + height(x)$ ;
 $depth(v) \leftarrow depth(z) + shift\_down$ ;  $width(v) \leftarrow width(x)$ ; { this also equals  $width(z)$  }
if  $thickness(q) = 0$  then
  begin  $p \leftarrow new\_kern((shift\_up - depth(x)) - (height(z) - shift\_down))$ ;  $link(p) \leftarrow z$ ;
  end
else begin  $y \leftarrow fraction\_rule(thickness(q))$ ;
   $p \leftarrow new\_kern((axis\_height(cur\_size) - delta) - (height(z) - shift\_down))$ ;
   $link(y) \leftarrow p$ ;  $link(p) \leftarrow z$ ;
   $p \leftarrow new\_kern((shift\_up - depth(x)) - (axis\_height(cur\_size) + delta))$ ;  $link(p) \leftarrow y$ ;
  end;
 $link(x) \leftarrow p$ ;  $list\_ptr(v) \leftarrow x$ 

```

This code is used in section 917.

922. \langle Put the fraction into a box with its delimiters, and make *new_hlist*(*q*) point to it 922 $\rangle \equiv$
if *cur_style* < *text_style* **then** *delta* \leftarrow *delim1*(*cur_size*)
else *delta* \leftarrow *delim2*(*cur_size*);
x \leftarrow *var_delimiter*(*left_delimiter*(*q*), *cur_size*, *delta*); *link*(*x*) \leftarrow *v*;
z \leftarrow *var_delimiter*(*right_delimiter*(*q*), *cur_size*, *delta*); *link*(*v*) \leftarrow *z*;
new_hlist(*q*) \leftarrow *hpack*(*x*, *natural*)

This code is used in section 917.

923. If the nucleus of an *op_noad* is a single character, it is to be centered vertically with respect to the axis, after first being enlarged (via a character list in the font) if we are in display style. The normal convention for placing displayed limits is to put them above and below the operator in display style.

The italic correction is removed from the character if there is a subscript and the limits are not being displayed. The *make_op* routine returns the value that should be used as an offset between subscript and superscript.

After *make_op* has acted, *subtype*(*q*) will be *limits* if and only if the limits have been set above and below the operator. In that case, *new_hlist*(*q*) will already contain the desired final box.

\langle Declare math construction procedures 908 $\rangle + \equiv$

function *make_op*(*q* : *pointer*): *scaled*;
var *delta*: *scaled*; { offset between subscript and superscript }
p, v, x, y, z: *pointer*; { temporary registers for box construction }
c: *quarterword*; *i*: *four_quarters*; { registers for character examination }
shift_up, shift_down: *scaled*; { dimensions for box calculation }
begin if (*subtype*(*q*) = *normal*) \wedge (*cur_style* < *text_style*) **then** *subtype*(*q*) \leftarrow *limits*;
if *math_type*(*nucleus*(*q*)) = *math_char* **then**
 begin fetch(*nucleus*(*q*));
 if (*cur_style* < *text_style*) \wedge (*char_tag*(*cur_i*) = *list_tag*) **then** { make it larger }
 begin *c* \leftarrow *rem_byte*(*cur_i*); *i* \leftarrow *char_info*(*cur_f*)(*c*);
 if *char_exists*(*i*) **then**
 begin *cur_c* \leftarrow *c*; *cur_i* \leftarrow *i*; *character*(*nucleus*(*q*)) \leftarrow *c*;
 end;
 end;
 delta \leftarrow *char_italic*(*cur_f*)(*cur_i*); *x* \leftarrow *clean_box*(*nucleus*(*q*), *cur_style*);
 if (*math_type*(*subscr*(*q*)) \neq *empty*) \wedge (*subtype*(*q*) \neq *limits*) **then** *width*(*x*) \leftarrow *width*(*x*) - *delta*;
 { remove italic correction }
 shift_amount(*x*) \leftarrow *half*(*height*(*x*) - *depth*(*x*)) - *axis_height*(*cur_size*); { center vertically }
 math_type(*nucleus*(*q*)) \leftarrow *sub_box*; *info*(*nucleus*(*q*)) \leftarrow *x*;
 end
else *delta* \leftarrow 0;
if *subtype*(*q*) = *limits* **then** \langle Construct a box with limits above and below it, skewed by *delta* 924 \rangle ;
 make_op \leftarrow *delta*;
end;

924. The following program builds a vlist box v for displayed limits. The width of the box is not affected by the fact that the limits may be skewed.

```

⟨ Construct a box with limits above and below it, skewed by  $\delta$  924 ⟩ ≡
  begin  $x \leftarrow \text{clean\_box}(\text{supscr}(q), \text{sup\_style}(\text{cur\_style}))$ ;  $y \leftarrow \text{clean\_box}(\text{nucleus}(q), \text{cur\_style})$ ;
 $z \leftarrow \text{clean\_box}(\text{subscr}(q), \text{sub\_style}(\text{cur\_style}))$ ;  $v \leftarrow \text{new\_null\_box}$ ;  $\text{type}(v) \leftarrow \text{vlist\_node}$ ;
 $\text{width}(v) \leftarrow \text{width}(y)$ ;
if  $\text{width}(x) > \text{width}(v)$  then  $\text{width}(v) \leftarrow \text{width}(x)$ ;
if  $\text{width}(z) > \text{width}(v)$  then  $\text{width}(v) \leftarrow \text{width}(z)$ ;
 $x \leftarrow \text{rebox}(x, \text{width}(v))$ ;  $y \leftarrow \text{rebox}(y, \text{width}(v))$ ;  $z \leftarrow \text{rebox}(z, \text{width}(v))$ ;
 $\text{shift\_amount}(x) \leftarrow \text{half}(\delta)$ ;  $\text{shift\_amount}(z) \leftarrow -\text{shift\_amount}(x)$ ;  $\text{height}(v) \leftarrow \text{height}(y)$ ;
 $\text{depth}(v) \leftarrow \text{depth}(y)$ ;
⟨ Attach the limits to  $y$  and adjust  $\text{height}(v)$ ,  $\text{depth}(v)$  to account for their presence 925 ⟩;
 $\text{new\_hlist}(q) \leftarrow v$ ;
end

```

This code is used in section 923.

925. We use shift_up and shift_down in the following program for the amount of glue between the displayed operator y and its limits x and z . The vlist inside box v will consist of x followed by y followed by z , with kern nodes for the spaces between and around them.

```

⟨ Attach the limits to  $y$  and adjust  $\text{height}(v)$ ,  $\text{depth}(v)$  to account for their presence 925 ⟩ ≡
if  $\text{math\_type}(\text{supscr}(q)) = \text{empty}$  then
  begin  $\text{free\_node}(x, \text{box\_node\_size})$ ;  $\text{list\_ptr}(v) \leftarrow y$ ;
  end
else begin  $\text{shift\_up} \leftarrow \text{big\_op\_spacing3} - \text{depth}(x)$ ;
  if  $\text{shift\_up} < \text{big\_op\_spacing1}$  then  $\text{shift\_up} \leftarrow \text{big\_op\_spacing1}$ ;
   $p \leftarrow \text{new\_kern}(\text{shift\_up})$ ;  $\text{link}(p) \leftarrow y$ ;  $\text{link}(x) \leftarrow p$ ;
   $p \leftarrow \text{new\_kern}(\text{big\_op\_spacing5})$ ;  $\text{link}(p) \leftarrow x$ ;  $\text{list\_ptr}(v) \leftarrow p$ ;
   $\text{height}(v) \leftarrow \text{height}(v) + \text{big\_op\_spacing5} + \text{height}(x) + \text{depth}(x) + \text{shift\_up}$ ;
  end;
if  $\text{math\_type}(\text{subscr}(q)) = \text{empty}$  then  $\text{free\_node}(z, \text{box\_node\_size})$ 
else begin  $\text{shift\_down} \leftarrow \text{big\_op\_spacing4} - \text{height}(z)$ ;
  if  $\text{shift\_down} < \text{big\_op\_spacing2}$  then  $\text{shift\_down} \leftarrow \text{big\_op\_spacing2}$ ;
   $p \leftarrow \text{new\_kern}(\text{shift\_down})$ ;  $\text{link}(y) \leftarrow p$ ;  $\text{link}(p) \leftarrow z$ ;
   $p \leftarrow \text{new\_kern}(\text{big\_op\_spacing5})$ ;  $\text{link}(z) \leftarrow p$ ;
   $\text{depth}(v) \leftarrow \text{depth}(v) + \text{big\_op\_spacing5} + \text{height}(z) + \text{depth}(z) + \text{shift\_down}$ ;
  end

```

This code is used in section 924.

926. A ligature found in a math formula does not create a *ligature_node*, because there is no question of hyphenation afterwards; the ligature will simply be stored in an ordinary *char_node*, after residing in an *ord_noad*.

The *math_type* is converted to *math_text_char* here if we would not want to apply an italic correction to the current character unless it belongs to a math font (i.e., a font with *space* = 0).

No boundary characters enter into these ligatures.

⟨ Declare math construction procedures 908 ⟩ +≡

procedure *make_ord*(*q* : *pointer*);

label *restart*, *exit*;

var *a*: *integer*; { address of lig/kern instruction }

p, r: *pointer*; { temporary registers for list manipulation }

begin *restart*:

if *math_type*(*subscr*(*q*)) = *empty* **then**

if *math_type*(*supscr*(*q*)) = *empty* **then**

if *math_type*(*nucleus*(*q*)) = *math_char* **then**

begin *p* ← *link*(*q*);

if *p* ≠ *null* **then**

if (*type*(*p*) ≥ *ord_noad*) ∧ (*type*(*p*) ≤ *punct_noad*) **then**

if *math_type*(*nucleus*(*p*)) = *math_char* **then**

if *fam*(*nucleus*(*p*)) = *fam*(*nucleus*(*q*)) **then**

begin *math_type*(*nucleus*(*q*)) ← *math_text_char*; *fetch*(*nucleus*(*q*));

if *char_tag*(*cur_i*) = *lig_tag* **then**

begin *a* ← *lig_kern_start*(*cur_f*)(*cur_i*); *cur_c* ← *character*(*nucleus*(*p*));

cur_i ← *font_info*[*a*].*qqqq*;

if *skip_byte*(*cur_i*) > *stop_flag* **then**

begin *a* ← *lig_kern_restart*(*cur_f*)(*cur_i*); *cur_i* ← *font_info*[*a*].*qqqq*;

end;

loop begin ⟨ If instruction *cur_i* is a kern with *cur_c*, attach the kern after *q*; or if it is a ligature with *cur_c*, combine noads *q* and *p* appropriately; then **return** if the cursor has moved past a noad, or **goto** *restart* 927 ⟩;

if *skip_byte*(*cur_i*) ≥ *stop_flag* **then return**;

a ← *a* + *qo*(*skip_byte*(*cur_i*)) + 1; *cur_i* ← *font_info*[*a*].*qqqq*;

end;

end;

end;

end;

exit: end;

927. Note that a ligature between an *ord_noad* and another kind of noad is replaced by an *ord_noad*, when the two noads collapse into one. But we could make a parenthesis (say) change shape when it follows certain letters. Presumably a font designer will define such ligatures only when this convention makes sense.

⟨If instruction *cur_i* is a kern with *cur_c*, attach the kern after *q*; or if it is a ligature with *cur_c*, combine noads *q* and *p* appropriately; then **return** if the cursor has moved past a noad, or **goto** *restart* 927⟩ ≡

```

if next_char(cur_i) = cur_c then
  if skip_byte(cur_i) ≤ stop_flag then
    if op_byte(cur_i) ≥ kern_flag then
      begin p ← new_kern(char_kern(cur_f)(cur_i)); link(p) ← link(q); link(q) ← p; return;
    end
  else begin check_interrupt; { allow a way out of infinite ligature loop }
    case op_byte(cur_i) of
      qi(1), qi(5): character(nucleus(q)) ← rem_byte(cur_i); { =: |, =: |> }
      qi(2), qi(6): character(nucleus(p)) ← rem_byte(cur_i); { |=:, |=:> }
      qi(3), qi(7), qi(11): begin r ← new_noad; { |=: |, |=: |>, |=: |>> }
        character(nucleus(r)) ← rem_byte(cur_i); fam(nucleus(r)) ← fam(nucleus(q));
        link(q) ← r; link(r) ← p;
        if op_byte(cur_i) < qi(11) then math_type(nucleus(r)) ← math_char
        else math_type(nucleus(r)) ← math_text_char; { prevent combination }
        end;
      othercases begin link(q) ← link(p); character(nucleus(q)) ← rem_byte(cur_i); { =: }
        mem[subscr(q)] ← mem[subscr(p)]; mem[supscr(q)] ← mem[supscr(p)];
        free_node(p, noad_size);
      end
    endcases;
    if op_byte(cur_i) > qi(3) then return;
    math_type(nucleus(q)) ← math_char; goto restart;
  end

```

This code is used in section 926.

928. When we get to the following part of the program, we have “fallen through” from cases that did not lead to *check_dimensions* or *done_with_noad* or *done_with_node*. Thus, q points to a noad whose nucleus may need to be converted to an hlist, and whose subscripts and superscripts need to be appended if they are present.

If *nucleus*(q) is not a *math_char*, the variable *delta* is the amount by which a superscript should be moved right with respect to a subscript when both are present.

```

⟨ Convert nucleus( $q$ ) to an hlist and attach the sub/superscripts 928 ⟩ ≡
  case math_type(nucleus( $q$ )) of
    math_char, math_text_char: ⟨ Create a character node  $p$  for nucleus( $q$ ), possibly followed by a kern node
      for the italic correction, and set delta to the italic correction if a subscript is present 929 ⟩;
    empty:  $p \leftarrow \text{null}$ ;
    sub_box:  $p \leftarrow \text{info}(\text{nucleus}(q))$ ;
    sub_mlist: begin  $\text{cur\_mlist} \leftarrow \text{info}(\text{nucleus}(q))$ ;  $\text{save\_style} \leftarrow \text{cur\_style}$ ;  $\text{mlist\_penalties} \leftarrow \text{false}$ ;
      mlist_to_hlist; { recursive call }
       $\text{cur\_style} \leftarrow \text{save\_style}$ ; ⟨ Set up the values of cur_size and cur_mu, based on cur_style 877 ⟩;
       $p \leftarrow \text{hpack}(\text{link}(\text{temp\_head}), \text{natural})$ ;
    end;
  othercases confusion("mlist2")
endcases;
 $\text{new\_hlist}(q) \leftarrow p$ ;
if ( $\text{math\_type}(\text{subscr}(q)) = \text{empty}$ )  $\wedge$  ( $\text{math\_type}(\text{supscr}(q)) = \text{empty}$ ) then goto check_dimensions;
make_scripts( $q$ , delta)

```

This code is used in section 902.

929. ⟨ Create a character node p for *nucleus*(q), possibly followed by a kern node for the italic correction, and set *delta* to the italic correction if a subscript is present 929 ⟩ ≡

```

begin fetch(nucleus( $q$ ));
if char_exists(cur_i) then
  begin  $\text{delta} \leftarrow \text{char\_italic}(\text{cur\_f})(\text{cur\_i})$ ;  $p \leftarrow \text{new\_character}(\text{cur\_f}, \text{qo}(\text{cur\_c}))$ ;
  if ( $\text{math\_type}(\text{nucleus}(q)) = \text{math\_text\_char}$ )  $\wedge$  ( $\text{space}(\text{cur\_f}) \neq 0$ ) then  $\text{delta} \leftarrow 0$ ;
    { no italic correction in mid-word of text font }
  if ( $\text{math\_type}(\text{subscr}(q)) = \text{empty}$ )  $\wedge$  ( $\text{delta} \neq 0$ ) then
    begin  $\text{link}(p) \leftarrow \text{new\_kern}(\text{delta})$ ;  $\text{delta} \leftarrow 0$ ;
    end;
  end
else  $p \leftarrow \text{null}$ ;
end

```

This code is used in section 928.

930. The purpose of *make_scripts*(*q*, *delta*) is to attach the subscript and/or superscript of noad *q* to the list that starts at *new_hlist*(*q*), given that the subscript and superscript aren't both empty. The superscript will appear to the right of the subscript by a given distance *delta*.

We set *shift_down* and *shift_up* to the minimum amounts to shift the baseline of subscripts and superscripts based on the given nucleus.

```

⟨Declare math construction procedures 908⟩ +≡
procedure make_scripts(q : pointer; delta : scaled);
  var p, x, y, z: pointer; {temporary registers for box construction}
    shift_up, shift_down, clr: scaled; {dimensions in the calculation}
    t: small_number; {subsidiary size code}
  begin p ← new_hlist(q);
  if is_char_node(p) then
    begin shift_up ← 0; shift_down ← 0;
    end
  else begin z ← hpack(p, natural);
    if cur_style < script_style then t ← script_size else t ← script_script_size;
    shift_up ← height(z) − sup_drop(t); shift_down ← depth(z) + sub_drop(t); free_node(z, box_node_size);
    end;
  if math_type(supscr(q)) = empty then ⟨Construct a subscript box x when there is no superscript 931⟩
  else begin ⟨Construct a superscript box x 932⟩;
    if math_type(subscr(q)) = empty then shift_amount(x) ← −shift_up
    else ⟨Construct a sub/superscript combination box x, with the superscript offset by delta 933⟩;
    end;
  if new_hlist(q) = null then new_hlist(q) ← x
  else begin p ← new_hlist(q);
    while link(p) ≠ null do p ← link(p);
    link(p) ← x;
    end;
  end;

```

931. When there is a subscript without a superscript, the top of the subscript should not exceed the baseline plus four-fifths of the x-height.

```

⟨Construct a subscript box x when there is no superscript 931⟩ ≡
  begin x ← clean_box(subscr(q), sub_style(cur_style)); width(x) ← width(x) + script_space;
  if shift_down < sub1(cur_size) then shift_down ← sub1(cur_size);
  clr ← height(x) − (abs(math_x_height(cur_size) * 4) div 5);
  if shift_down < clr then shift_down ← clr;
  shift_amount(x) ← shift_down;
  end

```

This code is used in section 930.

932. The bottom of a superscript should never descend below the baseline plus one-fourth of the x-height.

```

⟨Construct a superscript box  $x$  932⟩ ≡
  begin  $x \leftarrow \text{clean\_box}(\text{supscr}(q), \text{sup\_style}(\text{cur\_style})); \text{width}(x) \leftarrow \text{width}(x) + \text{script\_space};$ 
  if  $\text{odd}(\text{cur\_style})$  then  $\text{clr} \leftarrow \text{sup3}(\text{cur\_size})$ 
  else if  $\text{cur\_style} < \text{text\_style}$  then  $\text{clr} \leftarrow \text{sup1}(\text{cur\_size})$ 
    else  $\text{clr} \leftarrow \text{sup2}(\text{cur\_size});$ 
  if  $\text{shift\_up} < \text{clr}$  then  $\text{shift\_up} \leftarrow \text{clr};$ 
   $\text{clr} \leftarrow \text{depth}(x) + (\text{abs}(\text{math\_x\_height}(\text{cur\_size})) \text{ div } 4);$ 
  if  $\text{shift\_up} < \text{clr}$  then  $\text{shift\_up} \leftarrow \text{clr};$ 
  end

```

This code is used in section 930.

933. When both subscript and superscript are present, the subscript must be separated from the superscript by at least four times *default_rule_thickness*. If this condition would be violated, the subscript moves down, after which both subscript and superscript move up so that the bottom of the superscript is at least as high as the baseline plus four-fifths of the x-height.

```

⟨Construct a sub/superscript combination box  $x$ , with the superscript offset by  $\text{delta}$  933⟩ ≡
  begin  $y \leftarrow \text{clean\_box}(\text{subscr}(q), \text{sub\_style}(\text{cur\_style})); \text{width}(y) \leftarrow \text{width}(y) + \text{script\_space};$ 
  if  $\text{shift\_down} < \text{sub2}(\text{cur\_size})$  then  $\text{shift\_down} \leftarrow \text{sub2}(\text{cur\_size});$ 
   $\text{clr} \leftarrow 4 * \text{default\_rule\_thickness} - ((\text{shift\_up} - \text{depth}(x)) - (\text{height}(y) - \text{shift\_down}));$ 
  if  $\text{clr} > 0$  then
    begin  $\text{shift\_down} \leftarrow \text{shift\_down} + \text{clr};$ 
     $\text{clr} \leftarrow (\text{abs}(\text{math\_x\_height}(\text{cur\_size}) * 4) \text{ div } 5) - (\text{shift\_up} - \text{depth}(x));$ 
    if  $\text{clr} > 0$  then
      begin  $\text{shift\_up} \leftarrow \text{shift\_up} + \text{clr}; \text{shift\_down} \leftarrow \text{shift\_down} - \text{clr};$ 
      end;
    end;
   $\text{shift\_amount}(x) \leftarrow \text{delta};$  {superscript is  $\text{delta}$  to the right of the subscript}
   $p \leftarrow \text{new\_kern}((\text{shift\_up} - \text{depth}(x)) - (\text{height}(y) - \text{shift\_down})); \text{link}(x) \leftarrow p; \text{link}(p) \leftarrow y;$ 
   $x \leftarrow \text{vpack}(x, \text{natural}); \text{shift\_amount}(x) \leftarrow \text{shift\_down};$ 
  end

```

This code is used in section 930.

934. We have now tied up all the loose ends of the first pass of *mlist.to_hlist*. The second pass simply goes through and hooks everything together with the proper glue and penalties. It also handles the *left_noad* and *right_noad* that might be present, since *max_h* and *max_d* are now known. Variable *p* points to a node at the current end of the final hlist.

```

⟨Make a second pass over the mlist, removing all noads and inserting the proper spacing and penalties 934⟩ ≡
   $p \leftarrow \text{temp\_head}; \text{link}(p) \leftarrow \text{null}; q \leftarrow \text{mlist}; r\_type \leftarrow 0; \text{cur\_style} \leftarrow \text{style};$ 
  ⟨Set up the values of  $\text{cur\_size}$  and  $\text{cur\_mu}$ , based on  $\text{cur\_style}$  877⟩;
  while  $q \neq \text{null}$  do
    begin ⟨If node  $q$  is a style node, change the style and goto  $\text{delete\_q}$ ; otherwise if it is not a noad, put
      it into the hlist, advance  $q$ , and goto  $\text{done}$ ; otherwise set  $s$  to the size of noad  $q$ , set  $t$  to the
      associated type ( $\text{ord\_noad} \dots \text{inner\_noad}$ ), and set  $\text{pen}$  to the associated penalty 935⟩;
    ⟨Append inter-element spacing based on  $r\_type$  and  $t$  940⟩;
    ⟨Append any  $\text{new\_hlist}$  entries for  $q$ , and any appropriate penalties 941⟩;
    if  $\text{type}(q) = \text{right\_noad}$  then  $t \leftarrow \text{open\_noad};$ 
     $r\_type \leftarrow t;$ 
     $\text{delete\_q}: r \leftarrow q; q \leftarrow \text{link}(q); \text{free\_node}(r, s);$ 
     $\text{done}: \text{end}$ 
  end

```

This code is used in section 900.

935. Just before doing the big **case** switch in the second pass, the program sets up default values so that most of the branches are short.

```

⟨ If node  $q$  is a style node, change the style and goto delete_q; otherwise if it is not a noad, put it into the
  hlist, advance  $q$ , and goto done; otherwise set  $s$  to the size of noad  $q$ , set  $t$  to the associated type
  (ord_noad .. inner_noad), and set pen to the associated penalty 935)  $\equiv$ 
 $t \leftarrow \text{ord\_noad}$ ;  $s \leftarrow \text{noad\_size}$ ;  $\text{pen} \leftarrow \text{inf\_penalty}$ ;
case type( $q$ ) of
  op_noad, open_noad, close_noad, punct_noad, inner_noad:  $t \leftarrow \text{type}(q)$ ;
  bin_noad: begin  $t \leftarrow \text{bin\_noad}$ ;  $\text{pen} \leftarrow \text{bin\_op\_penalty}$ ;
    end;
  rel_noad: begin  $t \leftarrow \text{rel\_noad}$ ;  $\text{pen} \leftarrow \text{rel\_penalty}$ ;
    end;
  ord_noad, vcenter_noad, over_noad, under_noad: do_nothing;
  radical_noad:  $s \leftarrow \text{radical\_noad\_size}$ ;
  accent_noad:  $s \leftarrow \text{accent\_noad\_size}$ ;
  fraction_noad:  $s \leftarrow \text{fraction\_noad\_size}$ ;
  left_noad, right_noad:  $t \leftarrow \text{make\_left\_right}(q, \text{style}, \text{max\_d}, \text{max\_h})$ ;
  style_node: ⟨ Change the current style and goto delete_q 937 ⟩;
  whatsit_node, penalty_node, rule_node, disc_node, adjust_node, ins_node, mark_node, glue_node, kern_node:
    begin  $\text{link}(p) \leftarrow q$ ;  $p \leftarrow q$ ;  $q \leftarrow \text{link}(q)$ ;  $\text{link}(p) \leftarrow \text{null}$ ; goto done;
    end;
othercases confusion("mlist3")
endcases

```

This code is used in section 934.

936. The *make_left_right* function constructs a left or right delimiter of the required size and returns the value *open_noad* or *close_noad*. The *right_noad* and *left_noad* will both be based on the original *style*, so they will have consistent sizes.

We use the fact that $\text{right_noad} - \text{left_noad} = \text{close_noad} - \text{open_noad}$.

```

⟨ Declare math construction procedures 908 ⟩  $\equiv$ 
function make_left_right( $q$  : pointer; style : small_number; max_d, max_h : scaled): small_number;
  var delta, delta1, delta2: scaled; { dimensions used in the calculation }
  begin cur_style  $\leftarrow \text{style}$ ; ⟨ Set up the values of cur_size and cur_mu, based on cur_style 877 ⟩;
   $\text{delta2} \leftarrow \text{max\_d} + \text{axis\_height}(\text{cur\_size})$ ;  $\text{delta1} \leftarrow \text{max\_h} + \text{max\_d} - \text{delta2}$ ;
  if  $\text{delta2} > \text{delta1}$  then  $\text{delta1} \leftarrow \text{delta2}$ ; {  $\text{delta1}$  is max distance from axis }
   $\text{delta} \leftarrow (\text{delta1} \text{ div } 500) * \text{delimiter\_factor}$ ;  $\text{delta2} \leftarrow \text{delta1} + \text{delta1} - \text{delimiter\_shortfall}$ ;
  if  $\text{delta} < \text{delta2}$  then  $\text{delta} \leftarrow \text{delta2}$ ;
   $\text{new\_hlist}(q) \leftarrow \text{var\_delimiter}(\text{delimiter}(q), \text{cur\_size}, \text{delta})$ ;
   $\text{make\_left\_right} \leftarrow \text{type}(q) - (\text{left\_noad} - \text{open\_noad})$ ; { open_noad or close_noad }
  end;

```

937. ⟨ Change the current style and **goto** *delete_q* 937 ⟩ \equiv
begin *cur_style* $\leftarrow \text{subtype}(q)$; $s \leftarrow \text{style_node_size}$;
 ⟨ Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877 ⟩;
goto *delete_q*;
end

This code is used in section 935.

938. The inter-element spacing in math formulas depends on an 8×8 table that T_EX preloads as a 64-digit string. The elements of this string have the following significance:

- 0 means no space;
- 1 means a conditional thin space (`\nonscript\mskip\thinmuskip`);
- 2 means a thin space (`\mskip\thinmuskip`);
- 3 means a conditional medium space (`\nonscript\mskip\medmuskip`);
- 4 means a conditional thick space (`\nonscript\mskip\thickmuskip`);
- * means an impossible case.

This is all pretty cryptic, but *The T_EXbook* explains what is supposed to happen, and the string makes it happen.

A global variable *magic_offset* is computed so that if *a* and *b* are in the range *ord_noad* .. *inner_noad*, then *str_pool*[*a* * 8 + *b* + *magic_offset*] is the digit for spacing between noad types *a* and *b*.

If Pascal had provided a good way to preload constant arrays, this part of the program would not have been so strange.

```
define math_spacing =
"0234000122*4000133**3**344*0400400*000000234000111*1111112341011"
⟨Global variables 13⟩ +≡
magic_offset: integer; { used to find inter-element spacing }
```

939. ⟨Compute the magic offset 939⟩ ≡
magic_offset ← *str_start*[*math_spacing*] − 9 * *ord_noad*

This code is used in section 1515.

940. ⟨Append inter-element spacing based on *r_type* and *t* 940⟩ ≡
if *r_type* > 0 **then** { not the first noad }
 begin case *so*(*str_pool*[*r_type* * 8 + *t* + *magic_offset*]) **of**
 "0": *x* ← 0;
 "1": **if** *cur_style* < *script_style* **then** *x* ← *thin_mu_skip_code* **else** *x* ← 0;
 "2": *x* ← *thin_mu_skip_code*;
 "3": **if** *cur_style* < *script_style* **then** *x* ← *med_mu_skip_code* **else** *x* ← 0;
 "4": **if** *cur_style* < *script_style* **then** *x* ← *thick_mu_skip_code* **else** *x* ← 0;
 othercases *confusion*("mlist4")
 endcases;
if *x* ≠ 0 **then**
 begin *y* ← *math_glue*(*glue_par*(*x*), *cur_mu*); *z* ← *new_glue*(*y*); *glue_ref_count*(*y*) ← *null*;
 link(*p*) ← *z*; *p* ← *z*;
 subtype(*z*) ← *x* + 1; { store a symbolic subtype }
 end;
end

This code is used in section 934.

941. We insert a penalty node after the hlist entries of noad q if pen is not an “infinite” penalty, and if the node immediately following q is not a penalty node or a *rel_noad* or absent entirely.

\langle Append any *new_hlist* entries for q , and any appropriate penalties 941 $\rangle \equiv$

```

if new_hlist( $q$ )  $\neq$  null then
  begin link( $p$ )  $\leftarrow$  new_hlist( $q$ );
  repeat  $p \leftarrow$  link( $p$ );
  until link( $p$ ) = null;
  end;
if penalties then
  if link( $q$ )  $\neq$  null then
    if  $pen < inf\_penalty$  then
      begin r_type  $\leftarrow$  type(link( $q$ ));
      if r_type  $\neq$  penalty_node then
        if r_type  $\neq$  rel_noad then
          begin  $z \leftarrow new\_penalty(pen)$ ; link( $p$ )  $\leftarrow$   $z$ ;  $p \leftarrow z$ ;
          end;
        end
      end
    end
  end

```

This code is used in section 934.

942. Alignment. It’s sort of a miracle whenever `\halign` and `\valign` work, because they cut across so many of the control structures of TeX.

Therefore the present page is probably not the best place for a beginner to start reading this program; it is better to master everything else first.

Let us focus our thoughts on an example of what the input might be, in order to get some idea about how the alignment miracle happens. The example doesn’t do anything useful, but it is sufficiently general to indicate all of the special cases that must be dealt with; please do not be disturbed by its apparent complexity and meaninglessness.

```
\tabskip 2pt plus 3pt
\halign to 300pt{u1#v1&
      \tabskip 1pt plus 1fil u2#v2&
      u3#v3\cr
      a1&\omit a2&\vrule\cr
      \noalign{\vskip 3pt}
      b1\span b2\cr
      \omit&c2\span\omit\cr}
```

Here’s what happens:

(0) When `\halign to 300pt{` is scanned, the *scan_spec* routine places the 300pt dimension onto the *save_stack*, and an *align_group* code is placed above it. This will make it possible to complete the alignment when the matching `}` is found.

(1) The preamble is scanned next. Macros in the preamble are not expanded, except as part of a *tabskip* specification. For example, if `u2` had been a macro in the preamble above, it would have been expanded, since TeX must look for `minus...` as part of the *tabskip* glue. A “preamble list” is constructed based on the user’s preamble; in our case it contains the following seven items:

<code>\glue 2pt plus 3pt</code>	(the <i>tabskip</i> preceding column 1)
<code>\alignrecord, width -∞</code>	(preamble info for column 1)
<code>\glue 2pt plus 3pt</code>	(the <i>tabskip</i> between columns 1 and 2)
<code>\alignrecord, width -∞</code>	(preamble info for column 2)
<code>\glue 1pt plus 1fil</code>	(the <i>tabskip</i> between columns 2 and 3)
<code>\alignrecord, width -∞</code>	(preamble info for column 3)
<code>\glue 1pt plus 1fil</code>	(the <i>tabskip</i> following column 3)

These “alignrecord” entries have the same size as an *unset_node*, since they will later be converted into such nodes. However, at the moment they have no *type* or *subtype* fields; they have *info* fields instead, and these *info* fields are initially set to the value *end_span*, for reasons explained below. Furthermore, the alignrecord nodes have no *height* or *depth* fields; these are renamed *u_part* and *v_part*, and they point to token lists for the templates of the alignment. For example, the *u_part* field in the first alignrecord points to the token list ‘`u1`’, i.e., the template preceding the ‘`#`’ for column 1.

(2) TeX now looks at what follows the `\cr` that ended the preamble. It is not ‘`\noalign`’ or ‘`\omit`’, so this input is put back to be read again, and the template ‘`u1`’ is fed to the scanner. Just before reading ‘`u1`’, TeX goes into restricted horizontal mode. Just after reading ‘`u1`’, TeX will see ‘`a1`’, and then (when the `&` is sensed) TeX will see ‘`v1`’. Then TeX scans an *endv* token, indicating the end of a column. At this point an *unset_node* is created, containing the contents of the current hlist (i.e., ‘`u1a1v1`’). The natural width of this unset node replaces the *width* field of the alignrecord for column 1; in general, the alignrecords will record the maximum natural width that has occurred so far in a given column.

(3) Since ‘`\omit`’ follows the ‘`&`’, the templates for column 2 are now bypassed. Again TeX goes into restricted horizontal mode and makes an *unset_node* from the resulting hlist; but this time the hlist contains simply ‘`a2`’. The natural width of the new unset box is remembered in the *width* field of the alignrecord for column 2.

(4) A third *unset_node* is created for column 3, using essentially the mechanism that worked for column 1; this unset box contains ‘`u3\vrule v3`’. The vertical rule in this case has running dimensions that will later

extend to the height and depth of the whole first row, since each *unset_node* in a row will eventually inherit the height and depth of its enclosing box.

(5) The first row has now ended; it is made into a single unset box comprising the following seven items:

```
\glue 2pt plus 3pt
\unsetbox for 1 column: u1a1v1
\glue 2pt plus 3pt
\unsetbox for 1 column: a2
\glue 1pt plus 1fil
\unsetbox for 1 column: u3\vrule v3
\glue 1pt plus 1fil
```

The width of this unset row is unimportant, but it has the correct height and depth, so the correct baselineskip glue will be computed as the row is inserted into a vertical list.

(6) Since ‘\noalign’ follows the current \cr, TeX appends additional material (in this case \vskip 3pt) to the vertical list. While processing this material, TeX will be in internal vertical mode, and *no_align_group* will be on *save_stack*.

(7) The next row produces an unset box that looks like this:

```
\glue 2pt plus 3pt
\unsetbox for 2 columns: u1b1v1u2b2v2
\glue 1pt plus 1fil
\unsetbox for 1 column: (empty)
\glue 1pt plus 1fil
```

The natural width of the unset box that spans columns 1 and 2 is stored in a “span node,” which we will explain later; the *info* field of the alignrecord for column 1 now points to the new span node, and the *info* of the span node points to *end_span*.

(8) The final row produces the unset box

```
\glue 2pt plus 3pt
\unsetbox for 1 column: (empty)
\glue 2pt plus 3pt
\unsetbox for 2 columns: u2c2v2
\glue 1pt plus 1fil
```

A new span node is attached to the alignrecord for column 2.

(9) The last step is to compute the true column widths and to change all the unset boxes to hboxes, appending the whole works to the vertical list that encloses the \halign. The rules for deciding on the final widths of each unset column box will be explained below.

Note that as \halign is being processed, we fearlessly give up control to the rest of TeX. At critical junctures, an alignment routine is called upon to step in and do some little action, but most of the time these routines just lurk in the background. It’s something like post-hypnotic suggestion.

943. We have mentioned that alignrecords contain no *height* or *depth* fields. Their *glue_sign* and *glue_order* are pre-empted as well, since it is necessary to store information about what to do when a template ends. This information is called the *extra_info* field.

```
define u_part(#)  $\equiv$  mem[# + height_offset].int { pointer to  $\langle u_j \rangle$  token list }
define v_part(#)  $\equiv$  mem[# + depth_offset].int { pointer to  $\langle v_j \rangle$  token list }
define extra_info(#)  $\equiv$  info(# + list_offset) { info to remember during template }
```

944. Alignments can occur within alignments, so a small stack is used to access the alignrecord information. At each level we have a *preamble* pointer, indicating the beginning of the preamble list; a *cur_align* pointer, indicating the current position in the preamble list; a *cur_span* pointer, indicating the value of *cur_align* at the beginning of a sequence of spanned columns; a *cur_loop* pointer, indicating the tabskip glue before an alignrecord that should be copied next if the current list is extended; and the *align_state* variable, which indicates the nesting of braces so that `\cr` and `\span` and tab marks are properly intercepted. There also are pointers *cur_head* and *cur_tail* to the head and tail of a list of adjustments being moved out from horizontal mode to vertical mode.

The current values of these seven quantities appear in global variables; when they have to be pushed down, they are stored in 5-word nodes, and *align_ptr* points to the topmost such node.

```
define preamble  $\equiv$  link(align_head) { the current preamble list }
define align_stack_node_size = 6 { number of mem words to save alignment states }

⟨Global variables 13⟩  $\equiv$ 
cur_align: pointer; { current position in preamble list }
cur_span: pointer; { start of currently spanned columns in preamble list }
cur_loop: pointer; { place to copy when extending a periodic preamble }
align_ptr: pointer; { most recently pushed-down alignment stack node }
cur_head, cur_tail: pointer; { adjustment list pointers }
cur_pre_head, cur_pre_tail: pointer; { pre-adjustment list pointers }
```

945. The *align_state* and *preamble* variables are initialized elsewhere.

```
⟨Set initial values of key variables 21⟩  $\equiv$ 
  align_ptr  $\leftarrow$  null; cur_align  $\leftarrow$  null; cur_span  $\leftarrow$  null; cur_loop  $\leftarrow$  null; cur_head  $\leftarrow$  null;
  cur_tail  $\leftarrow$  null; cur_pre_head  $\leftarrow$  null; cur_pre_tail  $\leftarrow$  null;
```

946. Alignment stack maintenance is handled by a pair of trivial routines called *push_alignment* and *pop_alignment*.

```
procedure push_alignment;
  var p: pointer; { the new alignment stack node }
  begin p  $\leftarrow$  get_node(align_stack_node_size); link(p)  $\leftarrow$  align_ptr; info(p)  $\leftarrow$  cur_align;
  llink(p)  $\leftarrow$  preamble; rlink(p)  $\leftarrow$  cur_span; mem[p + 2].int  $\leftarrow$  cur_loop; mem[p + 3].int  $\leftarrow$  align_state;
  info(p + 4)  $\leftarrow$  cur_head; link(p + 4)  $\leftarrow$  cur_tail; info(p + 5)  $\leftarrow$  cur_pre_head; link(p + 5)  $\leftarrow$  cur_pre_tail;
  align_ptr  $\leftarrow$  p; cur_head  $\leftarrow$  get_avail; cur_pre_head  $\leftarrow$  get_avail;
  end;

procedure pop_alignment;
  var p: pointer; { the top alignment stack node }
  begin free_avail(cur_head); free_avail(cur_pre_head); p  $\leftarrow$  align_ptr; cur_tail  $\leftarrow$  link(p + 4);
  cur_head  $\leftarrow$  info(p + 4); cur_pre_tail  $\leftarrow$  link(p + 5); cur_pre_head  $\leftarrow$  info(p + 5);
  align_state  $\leftarrow$  mem[p + 3].int; cur_loop  $\leftarrow$  mem[p + 2].int; cur_span  $\leftarrow$  rlink(p); preamble  $\leftarrow$  llink(p);
  cur_align  $\leftarrow$  info(p); align_ptr  $\leftarrow$  link(p); free_node(p, align_stack_node_size);
  end;
```

947. TeX has eight procedures that govern alignments: *init_align* and *fin_align* are used at the very beginning and the very end; *init_row* and *fin_row* are used at the beginning and end of individual rows; *init_span* is used at the beginning of a sequence of spanned columns (possibly involving only one column); *init_col* and *fin_col* are used at the beginning and end of individual columns; and *align_peek* is used after `\cr` to see whether the next item is `\noalign`.

We shall consider these routines in the order they are first used during the course of a complete `\halign`, namely *init_align*, *align_peek*, *init_row*, *init_span*, *init_col*, *fin_col*, *fin_row*, *fin_align*.

948. When `\halign` or `\valign` has been scanned in an appropriate mode, TeX calls *init_align*, whose task is to get everything off to a good start. This mostly involves scanning the preamble and putting its information into the preamble list.

```

⟨Declare the procedure called get_preamble_token 956⟩
procedure align_peek; forward;
procedure normal_paragraph; forward;
procedure init_align;
  label done, done1, done2, continue;
  var save_cs_ptr: pointer; { warning_index value for error messages }
    p: pointer; { for short-term temporary use }
  begin save_cs_ptr ← cur_cs; { \halign or \valign, usually }
  push_alignment; align_state ← -1000000; { enter a new alignment level }
  ⟨Check for improper alignment in displayed math 950⟩;
  push_nest; { enter a new semantic level }
  ⟨Change current mode to -vmode for \halign, -hmode for \valign 949⟩;
  scan_spec(align_group, false);
  ⟨Scan the preamble and record it in the preamble list 951⟩;
  new_save_level(align_group);
  if every_cr ≠ null then begin_token_list(every_cr, every_cr_text);
  align_peek; { look for \noalign or \omit }
end;

```

949. In vertical modes, *prev_depth* already has the correct value. But if we are in *mmode* (displayed formula mode), we reach out to the enclosing vertical mode for the *prev_depth* value that produces the correct baseline calculations.

```

⟨Change current mode to -vmode for \halign, -hmode for \valign 949⟩ ≡
  if mode = mmode then
    begin mode ← -vmode; prev_depth ← nest[nest_ptr - 2].aux_field.sc;
    end
  else if mode > 0 then negate(mode)

```

This code is used in section 948.

950. When `\halign` is used as a displayed formula, there should be no other pieces of mlists present.

```

⟨Check for improper alignment in displayed math 950⟩ ≡
  if (mode = mmode) ∧ ((tail ≠ head) ∨ (incomplete_noad ≠ null)) then
    begin print_err("Improper_"); print_esc("halign"); print("_inside_$$'s");
    help3("Displays_can_use_special_alignments_(like_\\eqalignno)")
    ("only_if_nothing_but_the_alignment_itself_is_between_$$'s.")
    ("So_I've_deleted_the_formulas_that_preceded_this_alignment."); error; flush_math;
    end

```

This code is used in section 948.

951. \langle Scan the preamble and record it in the *preamble* list 951 $\rangle \equiv$

```
preamble  $\leftarrow$  null; cur_align  $\leftarrow$  align_head; cur_loop  $\leftarrow$  null; scanner_status  $\leftarrow$  aligning;
warning_index  $\leftarrow$  save_cs_ptr; align_state  $\leftarrow$  -1000000; { at this point, cur_cmd = left_brace }
loop begin  $\langle$  Append the current tabskip glue to the preamble list 952  $\rangle$ ;
  if cur_cmd = car_ret then goto done; { \cr ends the preamble }
   $\langle$  Scan preamble text until cur_cmd is tab_mark or car_ret, looking for changes in the tabskip glue;
    append an alignrecord to the preamble list 953  $\rangle$ ;
end;
done: scanner_status  $\leftarrow$  normal
```

This code is used in section 948.

952. \langle Append the current tabskip glue to the preamble list 952 $\rangle \equiv$

```
link(cur_align)  $\leftarrow$  new_param_glue(tab_skip_code); cur_align  $\leftarrow$  link(cur_align)
```

This code is used in section 951.

953. \langle Scan preamble text until *cur_cmd* is *tab_mark* or *car_ret*, looking for changes in the tabskip glue; append an alignrecord to the preamble list 953 $\rangle \equiv$

```
 $\langle$  Scan the template  $\langle u_j \rangle$ , putting the resulting token list in hold_head 957  $\rangle$ ;
link(cur_align)  $\leftarrow$  new_null_box; cur_align  $\leftarrow$  link(cur_align); { a new alignrecord }
info(cur_align)  $\leftarrow$  end_span; width(cur_align)  $\leftarrow$  null_flag; u_part(cur_align)  $\leftarrow$  link(hold_head);
 $\langle$  Scan the template  $\langle v_j \rangle$ , putting the resulting token list in hold_head 958  $\rangle$ ;
v_part(cur_align)  $\leftarrow$  link(hold_head)
```

This code is used in section 951.

954. We enter ‘\span’ into *eqtb* with *tab_mark* as its command code, and with *span_code* as the command modifier. This makes T_EX interpret it essentially the same as an alignment delimiter like ‘&’, yet it is recognizably different when we need to distinguish it from a normal delimiter. It also turns out to be useful to give a special *cr_code* to ‘\cr’, and an even larger *cr_cr_code* to ‘\crcr’.

The end of a template is represented by two “frozen” control sequences called `\endtemplate`. The first has the command code *end_template*, which is $>$ *outer_call*, so it will not easily disappear in the presence of errors. The *get_x_token* routine converts the first into the second, which has *endv* as its command code.

```
define span_code = 256 { distinct from any character }
define cr_code = 257 { distinct from span_code and from any character }
define cr_cr_code = cr_code + 1 { this distinguishes \crcr from \cr }
define end_template_token  $\equiv$  cs_token_flag + frozen_end_template

 $\langle$  Put each of TEX’s primitives into the hash table 244  $\rangle + \equiv$ 
primitive("span", tab_mark, span_code);
primitive("cr", car_ret, cr_code); text(frozen_cr)  $\leftarrow$  "cr"; eqtb[frozen_cr]  $\leftarrow$  eqtb[cur_val];
primitive("crcr", car_ret, cr_cr_code); text(frozen_end_template)  $\leftarrow$  "endtemplate";
text(frozen_endv)  $\leftarrow$  "endtemplate"; eq_type(frozen_endv)  $\leftarrow$  endv; equiv(frozen_endv)  $\leftarrow$  null_list;
eq_level(frozen_endv)  $\leftarrow$  level_one;
eqtb[frozen_end_template]  $\leftarrow$  eqtb[frozen_endv]; eq_type(frozen_end_template)  $\leftarrow$  end_template;
```

955. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
tab_mark: if chr_code = span_code then print_esc("span")
else chr_cmd("alignment_tab_character");
car_ret: if chr_code = cr_code then print_esc("cr")
else print_esc("crcr");
```

956. The preamble is copied directly, except that `\tabskip` causes a change to the `tabskip` glue, thereby possibly expanding macros that immediately follow it. An appearance of `\span` also causes such an expansion.

Note that if the preamble contains ‘`\global\tabskip`’, the ‘`\global`’ token survives in the preamble and the ‘`\tabskip`’ defines new `tabskip` glue (locally).

```

⟨Declare the procedure called get_preamble_token 956⟩ ≡
procedure get_preamble_token;
  label restart;
  begin restart: get_token;
  while (cur_chr = span_code) ∧ (cur_cmd = tab_mark) do
    begin get_token; { this token will be expanded once }
    if cur_cmd > max_command then
      begin expand; get_token;
    end;
  end;
if cur_cmd = endv then fatal_error("(interwoven_alignment_preambles_are_not_allowed)");
if (cur_cmd = assign_glue) ∧ (cur_chr = glue_base + tab_skip_code) then
  begin scan_optional_equals; scan_glue(glue_val);
  if global_defs > 0 then geq_define(glue_base + tab_skip_code, glue_ref, cur_val)
  else eq_define(glue_base + tab_skip_code, glue_ref, cur_val);
  goto restart;
end;
end;

```

This code is used in section 948.

957. Spaces are eliminated from the beginning of a template.

```

⟨Scan the template ⟨uj⟩, putting the resulting token list in hold_head 957⟩ ≡
  p ← hold_head; link(p) ← null;
  loop begin get_preamble_token;
    if cur_cmd = mac_param then goto done1;
    if (cur_cmd ≤ car_ret) ∧ (cur_cmd ≥ tab_mark) ∧ (align_state = −1000000) then
      if (p = hold_head) ∧ (cur_loop = null) ∧ (cur_cmd = tab_mark) then cur_loop ← cur_align
      else begin print_err("Missing_#_inserted_in_alignment_preamble");
        help3("There_should_be_exactly_one_#_between_&`s_when_an")
        ("\"halign_or_valign_is_being_set_up.In_this_case_you_had")
        ("none,_so_I've_put_one_in;_maybe_that_will_work."); back_error; goto done1;
      end
    else if (cur_cmd ≠ spacer) ∨ (p ≠ hold_head) then
      begin link(p) ← get_avail; p ← link(p); info(p) ← cur_tok;
      end;
    end;
  done1:

```

This code is used in section 953.

958. \langle Scan the template $\langle v_j \rangle$, putting the resulting token list in *hold_head* 958 $\rangle \equiv$

```

p ← hold_head; link(p) ← null;
loop begin continue: get_preamble_token;
  if (cur_cmd ≤ car_ret) ∧ (cur_cmd ≥ tab_mark) ∧ (align_state = -1000000) then goto done2;
  if cur_cmd = mac_param then
    begin print_err("Only one # is allowed per tab");
    help3("There should be exactly one # between &`s, when an")
    (" \halign or \valign is being set up. In this case you had")
    (" more than one, so I'm ignoring all but the first."); error; goto continue;
  end;
  link(p) ← get_avail; p ← link(p); info(p) ← cur_tok;
end;
done2: link(p) ← get_avail; p ← link(p); info(p) ← end_template_token { put \endtemplate at the end }

```

This code is used in section 953.

959. The tricky part about alignments is getting the templates into the scanner at the right time, and recovering control when a row or column is finished.

We usually begin a row after each `\cr` has been sensed, unless that `\cr` is followed by `\noalign` or by the right brace that terminates the alignment. The *align_peek* routine is used to look ahead and do the right thing; it either gets a new row started, or gets a `\noalign` started, or finishes off the alignment.

\langle Declare the procedure called *align_peek* 959 $\rangle \equiv$

```

procedure align_peek;
  label restart;
  begin restart: align_state ← 1000000;
  repeat get_x_or_protected;
  until cur_cmd ≠ spacer;
  if cur_cmd = no_align then
    begin scan_left_brace; new_save_level(no_align_group);
    if mode = -vmode then normal_paragraph;
    end
  else if cur_cmd = right_brace then fin_align
    else if (cur_cmd = car_ret) ∧ (cur_chr = cr_cr_code) then goto restart { ignore \crrcr }
    else begin init_row; { start a new row }
      init_col; { start a new column and replace what we peeked at }
    end;
  end;
end;

```

This code is used in section 974.

960. To start a row (i.e., a ‘row’ that rhymes with ‘dough’ but not with ‘bough’), we enter a new semantic level, copy the first tabskip glue, and change from internal vertical mode to restricted horizontal mode or vice versa. The *space_factor* and *prev_depth* are not used on this semantic level, but we clear them to zero just to be tidy.

\langle Declare the procedure called *init_span* 961 \rangle

```

procedure init_row;
  begin push_nest; mode ← (-hmode - vmode) - mode;
  if mode = -hmode then space_factor ← 0 else prev_depth ← 0;
  tail.append(new_glue(glue_ptr(preamble))); subtype(tail) ← tab_skip_code + 1;
  cur_align ← link(preamble); cur_tail ← cur_head; cur_pre_tail ← cur_pre_head; init_span(cur_align);
end;

```

961. The parameter to *init_span* is a pointer to the alignrecord where the next column or group of columns will begin. A new semantic level is entered, so that the columns will generate a list for subsequent packaging.

⟨Declare the procedure called *init_span* 961⟩ ≡

```
procedure init_span(p : pointer);
  begin push_nest;
  if mode = -hmode then space_factor ← 1000
  else begin prev_depth ← pdf_ignored_dimen; normal_paragraph;
    end;
  cur_span ← p;
  end;
```

This code is used in section 960.

962. When a column begins, we assume that *cur_cmd* is either *omit* or else the current token should be put back into the input until the $\langle u_j \rangle$ template has been scanned. (Note that *cur_cmd* might be *tab_mark* or *car_ret*.) We also assume that *align_state* is approximately 1000000 at this time. We remain in the same mode, and start the template if it is called for.

```
procedure init_col;
  begin extra_info(cur_align) ← cur_cmd;
  if cur_cmd = omit then align_state ← 0
  else begin back_input; begin_token_list(u_part(cur_align), u_template);
    end; { now align_state = 1000000 }
  end;
```

963. The scanner sets *align_state* to zero when the $\langle u_j \rangle$ template ends. When a subsequent $\backslash\text{cr}$ or $\backslash\text{span}$ or tab mark occurs with *align_state* = 0, the scanner activates the following code, which fires up the $\langle v_j \rangle$ template. We need to remember the *cur_chr*, which is either *cr_cr_code*, *cr_code*, *span_code*, or a character code, depending on how the column text has ended.

This part of the program had better not be activated when the preamble to another alignment is being scanned, or when no alignment preamble is active.

⟨Insert the $\langle v_j \rangle$ template and **goto** *restart* 963⟩ ≡

```
begin if (scanner_status = aligning) ∨ (cur_align = null) then
  fatal_error("(interwoven_alignment_preambles_are_not_allowed)");
cur_cmd ← extra_info(cur_align); extra_info(cur_align) ← cur_chr;
if cur_cmd = omit then begin_token_list(omit_template, v_template)
else begin_token_list(v_part(cur_align), v_template);
align_state ← 1000000; goto restart;
end
```

This code is used in section 364.

964. The token list *omit_template* just referred to is a constant token list that contains the special control sequence $\backslash\text{endtemplate}$ only.

⟨Initialize the special list heads and constant nodes 964⟩ ≡

```
info(omit_template) ← end_template_token; { link(omit_template) = null }
```

See also sections 971, 994, 1156, and 1163.

This code is used in section 182.

965. When the *endv* command at the end of a $\langle v_j \rangle$ template comes through the scanner, things really start to happen; and it is the *fin_col* routine that makes them happen. This routine returns *true* if a row as well as a column has been finished.

```
function fin_col: boolean;
  label exit;
  var p: pointer; { the alignrecord after the current one }
      q, r: pointer; { temporary pointers for list manipulation }
      s: pointer; { a new span node }
      u: pointer; { a new unset box }
      w: scaled; { natural width }
      o: glue_ord; { order of infinity }
      n: halfword; { span counter }
  begin if cur_align = null then confusion("endv");
  q ← link(cur_align); if q = null then confusion("endv");
  if align_state < 500000 then fatal_error("(interwoven_alignment_preambles_are_not_allowed)");
  p ← link(q); { If the preamble list has been traversed, check that the row has ended 966 };
  if extra_info(cur_align) ≠ span_code then
    begin unsave; new_save_level(align_group);
    { Package an unset box for the current column and record its width 970 };
    { Copy the tabskip glue between columns 969 };
    if extra_info(cur_align) ≥ cr_code then
      begin fin_col ← true; return;
    end;
    init_span(p);
  end;
  align_state ← 1000000;
  repeat get_x_or_protected;
  until cur_cmd ≠ spacer;
  cur_align ← p; init_col; fin_col ← false;
exit: end;
```

966. { If the preamble list has been traversed, check that the row has ended 966 } ≡
if (*p* = *null*) ∧ (*extra_info*(*cur_align*) < *cr_code*) **then**
if *cur_loop* ≠ *null* **then** { Lengthen the preamble periodically 967 }
else **begin** *print_err*("Extra_alignment_tab_has_been_changed_to_"); *print_esc*("cr");
 help3("You_have_given_more_\span_or_\&_marks_than_there_were")
 ("in_the_preamble_to_the_\halign_or_\valign_now_in_progress.")
 ("So_I'll_assume_that_you_meant_to_type_\cr_instead."); *extra_info*(*cur_align*) ← *cr_code*;
 error;
end

This code is used in section 965.

967. { Lengthen the preamble periodically 967 } ≡
begin *link*(*q*) ← *new_null_box*; *p* ← *link*(*q*); { a new alignrecord }
info(*p*) ← *end_span*; *width*(*p*) ← *null_flag*; *cur_loop* ← *link*(*cur_loop*);
 { Copy the templates from node *cur_loop* into node *p* 968 };
cur_loop ← *link*(*cur_loop*); *link*(*p*) ← *new_glue*(*glue_ptr*(*cur_loop*)); *subtype*(*link*(*p*)) ← *tab_skip_code* + 1;
end

This code is used in section 966.

968. \langle Copy the templates from node *cur_loop* into node *p* 968 $\rangle \equiv$
 $q \leftarrow \text{hold_head}; r \leftarrow u_part(\text{cur_loop});$
while $r \neq \text{null}$ **do**
 begin $\text{link}(q) \leftarrow \text{get_avail}; q \leftarrow \text{link}(q); \text{info}(q) \leftarrow \text{info}(r); r \leftarrow \text{link}(r);$
 end;
 $\text{link}(q) \leftarrow \text{null}; u_part(p) \leftarrow \text{link}(\text{hold_head}); q \leftarrow \text{hold_head}; r \leftarrow v_part(\text{cur_loop});$
while $r \neq \text{null}$ **do**
 begin $\text{link}(q) \leftarrow \text{get_avail}; q \leftarrow \text{link}(q); \text{info}(q) \leftarrow \text{info}(r); r \leftarrow \text{link}(r);$
 end;
 $\text{link}(q) \leftarrow \text{null}; v_part(p) \leftarrow \text{link}(\text{hold_head})$

This code is used in section 967.

969. \langle Copy the tabskip glue between columns 969 $\rangle \equiv$
 $\text{tail_append}(\text{new_glue}(\text{glue_ptr}(\text{link}(\text{cur_align}))));$ $\text{subtype}(\text{tail}) \leftarrow \text{tab_skip_code} + 1$

This code is used in section 965.

970. \langle Package an unset box for the current column and record its width 970 $\rangle \equiv$
begin if $\text{mode} = -h\text{mode}$ **then**
 begin $\text{adjust_tail} \leftarrow \text{cur_tail}; \text{pre_adjust_tail} \leftarrow \text{cur_pre_tail}; u \leftarrow \text{hpack}(\text{link}(\text{head}), \text{natural});$
 $w \leftarrow \text{width}(u); \text{cur_tail} \leftarrow \text{adjust_tail}; \text{adjust_tail} \leftarrow \text{null}; \text{cur_pre_tail} \leftarrow \text{pre_adjust_tail};$
 $\text{pre_adjust_tail} \leftarrow \text{null};$
 end
else begin $u \leftarrow \text{vpackage}(\text{link}(\text{head}), \text{natural}, 0); w \leftarrow \text{height}(u);$
 end;
 $n \leftarrow \text{min_quarterword};$ { this represents a span count of 1 }
if $\text{cur_span} \neq \text{cur_align}$ **then** \langle Update width entry for spanned columns 972 \rangle
else if $w > \text{width}(\text{cur_align})$ **then** $\text{width}(\text{cur_align}) \leftarrow w;$
 $\text{type}(u) \leftarrow \text{unset_node}; \text{span_count}(u) \leftarrow n;$
 \langle Determine the stretch order 833 $\rangle;$
 $\text{glue_order}(u) \leftarrow o; \text{glue_stretch}(u) \leftarrow \text{total_stretch}[o];$
 \langle Determine the shrink order 839 $\rangle;$
 $\text{glue_sign}(u) \leftarrow o; \text{glue_shrink}(u) \leftarrow \text{total_shrink}[o];$
 $\text{pop_nest}; \text{link}(\text{tail}) \leftarrow u; \text{tail} \leftarrow u;$
end

This code is used in section 965.

971. A span node is a 2-word record containing *width*, *info*, and *link* fields. The *link* field is not really a link, it indicates the number of spanned columns; the *info* field points to a span node for the same starting column, having a greater extent of spanning, or to *end_span*, which has the largest possible *link* field; the *width* field holds the largest natural width corresponding to a particular set of spanned columns.

A list of the maximum widths so far, for spanned columns starting at a given column, begins with the *info* field of the alignrecord for that column.

define $\text{span_node_size} = 2$ { number of *mem* words for a span node }

\langle Initialize the special list heads and constant nodes 964 $\rangle + \equiv$

$\text{link}(\text{end_span}) \leftarrow \text{max_quarterword} + 1; \text{info}(\text{end_span}) \leftarrow \text{null};$

972. \langle Update width entry for spanned columns 972 $\rangle \equiv$

```

begin  $q \leftarrow cur\_span$ ;
repeat  $incr(n)$ ;  $q \leftarrow link(link(q))$ ;
until  $q = cur\_align$ ;
if  $n > max\_quarterword$  then  $confusion("256\_spans")$ ; { this can happen, but won't }
 $q \leftarrow cur\_span$ ;
while  $link(info(q)) < n$  do  $q \leftarrow info(q)$ ;
if  $link(info(q)) > n$  then
  begin  $s \leftarrow get\_node(span\_node\_size)$ ;  $info(s) \leftarrow info(q)$ ;  $link(s) \leftarrow n$ ;  $info(q) \leftarrow s$ ;  $width(s) \leftarrow w$ ;
  end
else if  $width(info(q)) < w$  then  $width(info(q)) \leftarrow w$ ;
end

```

This code is used in section 970.

973. At the end of a row, we append an unset box to the current vlist (for `\halign`) or the current hlist (for `\valign`). This unset box contains the unset boxes for the columns, separated by the tabskip glue. Everything will be set later.

procedure *fin_row*;

```

var  $p$ : pointer; { the new unset box }
begin if  $mode = -hmode$  then
  begin  $p \leftarrow hpack(link(head), natural)$ ;  $pop\_nest$ ;
  if  $cur\_pre\_head \neq cur\_pre\_tail$  then  $append\_list(cur\_pre\_head)(cur\_pre\_tail)$ ;
   $append\_to\_vlist(p)$ ;
  if  $cur\_head \neq cur\_tail$  then  $append\_list(cur\_head)(cur\_tail)$ ;
  end
else begin  $p \leftarrow vpack(link(head), natural)$ ;  $pop\_nest$ ;  $link(tail) \leftarrow p$ ;  $tail \leftarrow p$ ;  $space\_factor \leftarrow 1000$ ;
  end;
 $type(p) \leftarrow unset\_node$ ;  $glue\_stretch(p) \leftarrow 0$ ;
if  $every\_cr \neq null$  then  $begin\_token\_list(every\_cr, every\_cr\_text)$ ;
 $align\_peek$ ;
end; { note that  $glue\_shrink(p) = 0$  since  $glue\_shrink \equiv shift\_amount$  }

```


974. Finally, we will reach the end of the alignment, and we can breathe a sigh of relief that memory hasn't overflowed. All the unset boxes will now be set so that the columns line up, taking due account of spanned columns.

```

procedure do_assignments; forward;
procedure resume_after_display; forward;
procedure build_page; forward;
procedure fin_align;
  var p, q, r, s, u, v: pointer; { registers for the list operations }
  t, w: scaled; { width of column }
  o: scaled; { shift offset for unset boxes }
  n: halfword; { matching span amount }
  rule_save: scaled; { temporary storage for overfull_rule }
  aux_save: memory_word; { temporary storage for aux }
  begin if cur_group  $\neq$  align_group then confusion("align1");
  unsave; { that align_group was for individual entries }
  if cur_group  $\neq$  align_group then confusion("align0");
  unsave; { that align_group was for the whole alignment }
  if nest[nest_ptr - 1].mode_field = mmode then o  $\leftarrow$  display_indent
  else o  $\leftarrow$  0;
  < Go through the preamble list, determining the column widths and changing the alignrecords to dummy
    unset boxes 975 >;
  < Package the preamble list, to determine the actual tabskip glue amounts, and let p point to this
    prototype box 978 >;
  < Set the glue in all the unset boxes of the current list 979 >;
  flush_node_list(p); pop_alignment; < Insert the current list into its environment 986 >;
  end;
< Declare the procedure called align_peek 959 >

```

975. It's time now to dismantle the preamble list and to compute the column widths. Let w_{ij} be the maximum of the natural widths of all entries that span columns i through j , inclusive. The alignrecord for column i contains w_{ii} in its *width* field, and there is also a linked list of the nonzero w_{ij} for increasing j , accessible via the *info* field; these span nodes contain the value $j - i + \text{min_quarterword}$ in their *link* fields. The values of w_{ii} were initialized to *null_flag*, which we regard as $-\infty$.

The final column widths are defined by the formula

$$w_j = \max_{1 \leq i \leq j} \left(w_{ij} - \sum_{i \leq k < j} (t_k + w_k) \right),$$

where t_k is the natural width of the tabskip glue between columns k and $k + 1$. However, if $w_{ij} = -\infty$ for all i in the range $1 \leq i \leq j$ (i.e., if every entry that involved column j also involved column $j + 1$), we let $w_j = 0$, and we zero out the tabskip glue after column j .

TeX computes these values by using the following scheme: First $w_1 = w_{11}$. Then replace w_{2j} by $\max(w_{2j}, w_{1j} - t_1 - w_1)$, for all $j > 1$. Then $w_2 = w_{22}$. Then replace w_{3j} by $\max(w_{3j}, w_{2j} - t_2 - w_2)$ for all $j > 2$; and so on. If any w_j turns out to be $-\infty$, its value is changed to zero and so is the next tabskip.

```

⟨Go through the preamble list, determining the column widths and changing the alignrecords to dummy
  unset boxes 975⟩ ≡
   $q \leftarrow \text{link}(\text{preamble});$ 
  repeat  $\text{flush\_list}(u\_part(q)); \text{flush\_list}(v\_part(q)); p \leftarrow \text{link}(\text{link}(q));$ 
    if  $\text{width}(q) = \text{null\_flag}$  then ⟨Nullify  $\text{width}(q)$  and the tabskip glue following this column 976⟩;
    if  $\text{info}(q) \neq \text{end\_span}$  then
      ⟨Merge the widths in the span nodes of  $q$  with those of  $p$ , destroying the span nodes of  $q$  977⟩;
       $\text{type}(q) \leftarrow \text{unset\_node}; \text{span\_count}(q) \leftarrow \text{min\_quarterword}; \text{height}(q) \leftarrow 0; \text{depth}(q) \leftarrow 0;$ 
       $\text{glue\_order}(q) \leftarrow \text{normal}; \text{glue\_sign}(q) \leftarrow \text{normal}; \text{glue\_stretch}(q) \leftarrow 0; \text{glue\_shrink}(q) \leftarrow 0; q \leftarrow p;$ 
  until  $q = \text{null}$ 

```

This code is used in section 974.

```

976. ⟨Nullify  $\text{width}(q)$  and the tabskip glue following this column 976⟩ ≡
  begin  $\text{width}(q) \leftarrow 0; r \leftarrow \text{link}(q); s \leftarrow \text{glue\_ptr}(r);$ 
  if  $s \neq \text{zero\_glue}$  then
    begin  $\text{add\_glue\_ref}(\text{zero\_glue}); \text{delete\_glue\_ref}(s); \text{glue\_ptr}(r) \leftarrow \text{zero\_glue};$ 
    end;
  end

```

This code is used in section 975.

977. Merging of two span-node lists is a typical exercise in the manipulation of linearly linked data structures. The essential invariant in the following **repeat** loop is that we want to dispense with node r , in q 's list, and u is its successor; all nodes of p 's list up to and including s have been processed, and the successor of s matches r or precedes r or follows r , according as $\text{link}(r) = n$ or $\text{link}(r) > n$ or $\text{link}(r) < n$.

\langle Merge the widths in the span nodes of q with those of p , destroying the span nodes of q 977 $\rangle \equiv$

```

begin  $t \leftarrow \text{width}(q) + \text{width}(\text{glue\_ptr}(\text{link}(q)))$ ;  $r \leftarrow \text{info}(q)$ ;  $s \leftarrow \text{end\_span}$ ;  $\text{info}(s) \leftarrow p$ ;
 $n \leftarrow \text{min\_quarterword} + 1$ ;
repeat  $\text{width}(r) \leftarrow \text{width}(r) - t$ ;  $u \leftarrow \text{info}(r)$ ;
  while  $\text{link}(r) > n$  do
    begin  $s \leftarrow \text{info}(s)$ ;  $n \leftarrow \text{link}(\text{info}(s)) + 1$ ;
    end;
  if  $\text{link}(r) < n$  then
    begin  $\text{info}(r) \leftarrow \text{info}(s)$ ;  $\text{info}(s) \leftarrow r$ ;  $\text{decr}(\text{link}(r))$ ;  $s \leftarrow r$ ;
    end
  else begin if  $\text{width}(r) > \text{width}(\text{info}(s))$  then  $\text{width}(\text{info}(s)) \leftarrow \text{width}(r)$ ;
     $\text{free\_node}(r, \text{span\_node\_size})$ ;
  end;
   $r \leftarrow u$ ;
until  $r = \text{end\_span}$ ;
end

```

This code is used in section 975.

978. Now the preamble list has been converted to a list of alternating unset boxes and tabskip glue, where the box widths are equal to the final column sizes. In case of `\valign`, we change the widths to heights, so that a correct error message will be produced if the alignment is overfull or underfull.

\langle Package the preamble list, to determine the actual tabskip glue amounts, and let p point to this prototype box 978 $\rangle \equiv$

```

 $\text{save\_ptr} \leftarrow \text{save\_ptr} - 2$ ;  $\text{pack\_begin\_line} \leftarrow -\text{mode\_line}$ ;
if  $\text{mode} = -\text{vmode}$  then
  begin  $\text{rule\_save} \leftarrow \text{overfull\_rule}$ ;  $\text{overfull\_rule} \leftarrow 0$ ; { prevent rule from being packaged }
   $p \leftarrow \text{hpack}(\text{preamble}, \text{saved}(1), \text{saved}(0))$ ;  $\text{overfull\_rule} \leftarrow \text{rule\_save}$ ;
  end
else begin  $q \leftarrow \text{link}(\text{preamble})$ ;
  repeat  $\text{height}(q) \leftarrow \text{width}(q)$ ;  $\text{width}(q) \leftarrow 0$ ;  $q \leftarrow \text{link}(\text{link}(q))$ ;
  until  $q = \text{null}$ ;
   $p \leftarrow \text{vpack}(\text{preamble}, \text{saved}(1), \text{saved}(0))$ ;  $q \leftarrow \text{link}(\text{preamble})$ ;
  repeat  $\text{width}(q) \leftarrow \text{height}(q)$ ;  $\text{height}(q) \leftarrow 0$ ;  $q \leftarrow \text{link}(\text{link}(q))$ ;
  until  $q = \text{null}$ ;
  end;
 $\text{pack\_begin\_line} \leftarrow 0$ 

```

This code is used in section 974.

979. \langle Set the glue in all the unset boxes of the current list 979 $\rangle \equiv$

```

 $q \leftarrow \text{link}(\text{head}); s \leftarrow \text{head};$ 
while  $q \neq \text{null}$  do
  begin if  $\neg \text{is\_char\_node}(q)$  then
    if  $\text{type}(q) = \text{unset\_node}$  then  $\langle$  Set the unset box  $q$  and the unset boxes in it 981  $\rangle$ 
    else if  $\text{type}(q) = \text{rule\_node}$  then
       $\langle$  Make the running dimensions in rule  $q$  extend to the boundaries of the alignment 980  $\rangle$ ;
     $s \leftarrow q; q \leftarrow \text{link}(q);$ 
  end

```

This code is used in section 974.

980. \langle Make the running dimensions in rule q extend to the boundaries of the alignment 980 $\rangle \equiv$

```

begin if  $\text{is\_running}(\text{width}(q))$  then  $\text{width}(q) \leftarrow \text{width}(p);$ 
if  $\text{is\_running}(\text{height}(q))$  then  $\text{height}(q) \leftarrow \text{height}(p);$ 
if  $\text{is\_running}(\text{depth}(q))$  then  $\text{depth}(q) \leftarrow \text{depth}(p);$ 
if  $o \neq 0$  then
  begin  $r \leftarrow \text{link}(q); \text{link}(q) \leftarrow \text{null}; q \leftarrow \text{hpack}(q, \text{natural}); \text{shift\_amount}(q) \leftarrow o; \text{link}(q) \leftarrow r;$ 
   $\text{link}(s) \leftarrow q;$ 
  end;
end

```

This code is used in section 979.

981. The unset box q represents a row that contains one or more unset boxes, depending on how soon `\cr` occurred in that row.

\langle Set the unset box q and the unset boxes in it 981 $\rangle \equiv$

```

begin if  $\text{mode} = -\text{vmode}$  then
  begin  $\text{type}(q) \leftarrow \text{hlist\_node}; \text{width}(q) \leftarrow \text{width}(p);$ 
  if  $\text{nest}[\text{nest\_ptr} - 1].\text{mode\_field} = \text{mmode}$  then  $\text{set\_box\_lr}(q)(\text{dlist});$  { for ship-out }
  end
else begin  $\text{type}(q) \leftarrow \text{vlist\_node}; \text{height}(q) \leftarrow \text{height}(p);$ 
  end;
 $\text{glue\_order}(q) \leftarrow \text{glue\_order}(p); \text{glue\_sign}(q) \leftarrow \text{glue\_sign}(p); \text{glue\_set}(q) \leftarrow \text{glue\_set}(p);$ 
 $\text{shift\_amount}(q) \leftarrow o; r \leftarrow \text{link}(\text{list\_ptr}(q)); s \leftarrow \text{link}(\text{list\_ptr}(p));$ 
repeat  $\langle$  Set the glue in node  $r$  and change it from an unset node 982  $\rangle$ ;
   $r \leftarrow \text{link}(\text{link}(r)); s \leftarrow \text{link}(\text{link}(s));$ 
until  $r = \text{null};$ 
end

```

This code is used in section 979.

982. A box made from spanned columns will be followed by tabskip glue nodes and by empty boxes as if there were no spanning. This permits perfect alignment of subsequent entries, and it prevents values that depend on floating point arithmetic from entering into the dimensions of any boxes.

```

⟨Set the glue in node  $r$  and change it from an unset node 982⟩ ≡
   $n \leftarrow \text{span\_count}(r)$ ;  $t \leftarrow \text{width}(s)$ ;  $w \leftarrow t$ ;  $u \leftarrow \text{hold\_head}$ ;  $\text{set\_box\_lr}(r)(0)$ ; { for ship_out }
  while  $n > \text{min\_quarterword}$  do
    begin  $\text{decr}(n)$ ; ⟨Append tabskip glue and an empty box to list  $u$ , and update  $s$  and  $t$  as the prototype
      nodes are passed 983⟩;
    end;
  if  $\text{mode} = -\text{vmode}$  then
    ⟨Make the unset node  $r$  into an hlist_node of width  $w$ , setting the glue as if the width were  $t$  984⟩
  else ⟨Make the unset node  $r$  into a vlist_node of height  $w$ , setting the glue as if the height were  $t$  985⟩;
   $\text{shift\_amount}(r) \leftarrow 0$ ;
  if  $u \neq \text{hold\_head}$  then { append blank boxes to account for spanned nodes }
    begin  $\text{link}(u) \leftarrow \text{link}(r)$ ;  $\text{link}(r) \leftarrow \text{link}(\text{hold\_head})$ ;  $r \leftarrow u$ ;
    end

```

This code is used in section 981.

```

983. ⟨Append tabskip glue and an empty box to list  $u$ , and update  $s$  and  $t$  as the prototype nodes are
  passed 983⟩ ≡
   $s \leftarrow \text{link}(s)$ ;  $v \leftarrow \text{glue\_ptr}(s)$ ;  $\text{link}(u) \leftarrow \text{new\_glue}(v)$ ;  $u \leftarrow \text{link}(u)$ ;  $\text{subtype}(u) \leftarrow \text{tab\_skip\_code} + 1$ ;
   $t \leftarrow t + \text{width}(v)$ ;
  if  $\text{glue\_sign}(p) = \text{stretching}$  then
    begin if  $\text{stretch\_order}(v) = \text{glue\_order}(p)$  then  $t \leftarrow t + \text{round}(\text{float}(\text{glue\_set}(p)) * \text{stretch}(v))$ ;
    end
  else if  $\text{glue\_sign}(p) = \text{shrinking}$  then
    begin if  $\text{shrink\_order}(v) = \text{glue\_order}(p)$  then  $t \leftarrow t - \text{round}(\text{float}(\text{glue\_set}(p)) * \text{shrink}(v))$ ;
    end;
   $s \leftarrow \text{link}(s)$ ;  $\text{link}(u) \leftarrow \text{new\_null\_box}$ ;  $u \leftarrow \text{link}(u)$ ;  $t \leftarrow t + \text{width}(s)$ ;
  if  $\text{mode} = -\text{vmode}$  then  $\text{width}(u) \leftarrow \text{width}(s)$  else begin  $\text{type}(u) \leftarrow \text{vlist\_node}$ ;  $\text{height}(u) \leftarrow \text{width}(s)$ ;
  end

```

This code is used in section 982.

```

984. ⟨Make the unset node  $r$  into an hlist_node of width  $w$ , setting the glue as if the width were  $t$  984⟩ ≡
  begin  $\text{height}(r) \leftarrow \text{height}(q)$ ;  $\text{depth}(r) \leftarrow \text{depth}(q)$ ;
  if  $t = \text{width}(r)$  then
    begin  $\text{glue\_sign}(r) \leftarrow \text{normal}$ ;  $\text{glue\_order}(r) \leftarrow \text{normal}$ ;  $\text{set\_glue\_ratio\_zero}(\text{glue\_set}(r))$ ;
    end
  else if  $t > \text{width}(r)$  then
    begin  $\text{glue\_sign}(r) \leftarrow \text{stretching}$ ;
    if  $\text{glue\_stretch}(r) = 0$  then  $\text{set\_glue\_ratio\_zero}(\text{glue\_set}(r))$ 
    else  $\text{glue\_set}(r) \leftarrow \text{unfloat}((t - \text{width}(r)) / \text{glue\_stretch}(r))$ ;
    end
  else begin  $\text{glue\_order}(r) \leftarrow \text{glue\_sign}(r)$ ;  $\text{glue\_sign}(r) \leftarrow \text{shrinking}$ ;
    if  $\text{glue\_shrink}(r) = 0$  then  $\text{set\_glue\_ratio\_zero}(\text{glue\_set}(r))$ 
    else if  $(\text{glue\_order}(r) = \text{normal}) \wedge (\text{width}(r) - t > \text{glue\_shrink}(r))$  then
       $\text{set\_glue\_ratio\_one}(\text{glue\_set}(r))$ 
    else  $\text{glue\_set}(r) \leftarrow \text{unfloat}((\text{width}(r) - t) / \text{glue\_shrink}(r))$ ;
    end;
   $\text{width}(r) \leftarrow w$ ;  $\text{type}(r) \leftarrow \text{hlist\_node}$ ;
  end

```

This code is used in section 982.

985. \langle Make the unset node r into a *vlist_node* of height w , setting the glue as if the height were t 985 $\rangle \equiv$

```

begin  $width(r) \leftarrow width(q)$ ;
if  $t = height(r)$  then
  begin  $glue\_sign(r) \leftarrow normal$ ;  $glue\_order(r) \leftarrow normal$ ;  $set\_glue\_ratio\_zero(glue\_set(r))$ ;
  end
else if  $t > height(r)$  then
  begin  $glue\_sign(r) \leftarrow stretching$ ;
  if  $glue\_stretch(r) = 0$  then  $set\_glue\_ratio\_zero(glue\_set(r))$ 
  else  $glue\_set(r) \leftarrow unfloat((t - height(r))/glue\_stretch(r))$ ;
  end
else begin  $glue\_order(r) \leftarrow glue\_sign(r)$ ;  $glue\_sign(r) \leftarrow shrinking$ ;
  if  $glue\_shrink(r) = 0$  then  $set\_glue\_ratio\_zero(glue\_set(r))$ 
  else if  $(glue\_order(r) = normal) \wedge (height(r) - t > glue\_shrink(r))$  then
     $set\_glue\_ratio\_one(glue\_set(r))$ 
     $glue\_set(r) \leftarrow unfloat((height(r) - t)/glue\_shrink(r))$ ;
  end;
   $height(r) \leftarrow w$ ;  $type(r) \leftarrow vlist\_node$ ;
end

```

This code is used in section 982.

986. We now have a completed alignment, in the list that starts at *head* and ends at *tail*. This list will be merged with the one that encloses it. (In case the enclosing mode is *mmode*, for displayed formulas, we will need to insert glue before and after the display; that part of the program will be deferred until we're more familiar with such operations.)

In restricted horizontal mode, the *clang* part of *aux* is undefined; an over-cautious Pascal runtime system may complain about this.

\langle Insert the current list into its environment 986 $\rangle \equiv$

```

 $aux\_save \leftarrow aux$ ;  $p \leftarrow link(head)$ ;  $q \leftarrow tail$ ;  $pop\_nest$ ;
if  $mode = mmode$  then  $\langle$  Finish an alignment in a display 1382  $\rangle$ 
else begin  $aux \leftarrow aux\_save$ ;  $link(tail) \leftarrow p$ ;
  if  $p \neq null$  then  $tail \leftarrow q$ ;
  if  $mode = vmode$  then  $build\_page$ ;
end

```

This code is used in section 974.

987. Breaking paragraphs into lines. We come now to what is probably the most interesting algorithm of TeX: the mechanism for choosing the “best possible” breakpoints that yield the individual lines of a paragraph. TeX’s line-breaking algorithm takes a given horizontal list and converts it to a sequence of boxes that are appended to the current vertical list. In the course of doing this, it creates a special data structure containing three kinds of records that are not used elsewhere in TeX. Such nodes are created while a paragraph is being processed, and they are destroyed afterwards; thus, the other parts of TeX do not need to know anything about how line-breaking is done.

The method used here is based on an approach devised by Michael F. Plass and the author in 1977, subsequently generalized and improved by the same two people in 1980. A detailed discussion appears in *Software—Practice and Experience* **11** (1981), 1119–1184, where it is shown that the line-breaking problem can be regarded as a special case of the problem of computing the shortest path in an acyclic network. The cited paper includes numerous examples and describes the history of line breaking as it has been practiced by printers through the ages. The present implementation adds two new ideas to the algorithm of 1980: Memory space requirements are considerably reduced by using smaller records for inactive nodes than for active ones, and arithmetic overflow is avoided by using “delta distances” instead of keeping track of the total distance from the beginning of the paragraph to the current point.

988. The *line_break* procedure should be invoked only in horizontal mode; it leaves that mode and places its output into the current vlist of the enclosing vertical mode (or internal vertical mode). There is one explicit parameter: *d* is true for partial paragraphs preceding display math mode; in this case the amount of additional penalty inserted before the final line is *display_widow_penalty* instead of *widow_penalty*.

There are also a number of implicit parameters: The hlist to be broken starts at *link(head)*, and it is nonempty. The value of *prev_graf* in the enclosing semantic level tells where the paragraph should begin in the sequence of line numbers, in case hanging indentation or `\parshape` is in use; *prev_graf* is zero unless this paragraph is being continued after a displayed formula. Other implicit parameters, such as the *par_shape_ptr* and various penalties to use for hyphenation, etc., appear in *eqtb*.

After *line_break* has acted, it will have updated the current vlist and the value of *prev_graf*. Furthermore, the global variable *just_box* will point to the final box created by *line_break*, so that the width of this line can be ascertained when it is necessary to decide whether to use *above_display_skip* or *above_display_short_skip* before a displayed formula.

⟨Global variables 13⟩ +≡

just_box: pointer; { the *hlist_node* for the last line of the new paragraph }

989. Since *line_break* is a rather lengthy procedure—sort of a small world unto itself—we must build it up little by little, somewhat more cautiously than we have done with the simpler procedures of TeX. Here is the general outline.

⟨Declare subprocedures for *line_break* 1000⟩

procedure *line_break*(*d* : boolean);

label *done*, *done1*, *done2*, *done3*, *done4*, *done5*, *continue*;

var ⟨Local variables for line breaking 1036⟩

begin *pack_begin_line* ← *mode_line*; { this is for over/underfull box messages }

 ⟨Get ready to start line breaking 990⟩;

 ⟨Find optimal breakpoints 1037⟩;

 ⟨Break the paragraph at the chosen breakpoints, justify the resulting lines to the correct widths, and append them to the current vertical list 1050⟩;

 ⟨Clean up the memory by removing the break nodes 1039⟩;

pack_begin_line ← 0;

end;

⟨Declare ε -TeX procedures for use by *main_control* 1653⟩

990. The first task is to move the list from *head* to *temp_head* and go into the enclosing semantic level. We also append the `\parfillskip` glue to the end of the paragraph, removing a space (or other glue node) if it was there, since spaces usually precede blank lines and instances of ‘`$$`’. The *par_fill_skip* is preceded by an infinite penalty, so it will never be considered as a potential breakpoint.

This code assumes that a *glue_node* and a *penalty_node* occupy the same number of *mem* words.

```

⟨Get ready to start line breaking 990⟩ ≡
  link(temp_head) ← link(head);
  if is_char_node(tail) then tail_append(new_penalty(inf_penalty))
  else if type(tail) ≠ glue_node then tail_append(new_penalty(inf_penalty))
    else begin type(tail) ← penalty_node; delete_glue_ref(glue_ptr(tail)); flush_node_list(leader_ptr(tail));
      penalty(tail) ← inf_penalty;
    end;
  link(tail) ← new_param_glue(par_fill_skip_code); last_line_fill ← link(tail);
  init_cur_lang ← prev_graf mod '200000; init_l_hyf ← prev_graf div '20000000;
  init_r_hyf ← (prev_graf div '200000) mod '100; pop_nest;

```

See also sections 1001, 1008, and 1022.

This code is used in section 989.

991. When looking for optimal line breaks, TeX creates a “break node” for each break that is *feasible*, in the sense that there is a way to end a line at the given place without requiring any line to stretch more than a given tolerance. A break node is characterized by three things: the position of the break (which is a pointer to a *glue_node*, *math_node*, *penalty_node*, or *disc_node*); the ordinal number of the line that will follow this breakpoint; and the fitness classification of the line that has just ended, i.e., *tight_fit*, *decent_fit*, *loose_fit*, or *very_loose_fit*.

```

define tight_fit = 3 { fitness classification for lines shrinking 0.5 to 1.0 of their shrinkability }
define loose_fit = 1 { fitness classification for lines stretching 0.5 to 1.0 of their stretchability }
define very_loose_fit = 0 { fitness classification for lines stretching more than their stretchability }
define decent_fit = 2 { fitness classification for all other lines }

```

992. The algorithm essentially determines the best possible way to achieve each feasible combination of position, line, and fitness. Thus, it answers questions like, “What is the best way to break the opening part of the paragraph so that the fourth line is a tight line ending at such-and-such a place?” However, the fact that all lines are to be the same length after a certain point makes it possible to regard all sufficiently large line numbers as equivalent, when the looseness parameter is zero, and this makes it possible for the algorithm to save space and time.

An “active node” and a “passive node” are created in *mem* for each feasible breakpoint that needs to be considered. Active nodes are three words long and passive nodes are two words long. We need active nodes only for breakpoints near the place in the paragraph that is currently being examined, so they are recycled within a comparatively short time after they are created.

993. An active node for a given breakpoint contains six fields:

link points to the next node in the list of active nodes; the last active node has *link* = *last_active*.

break_node points to the passive node associated with this breakpoint.

line_number is the number of the line that follows this breakpoint.

fitness is the fitness classification of the line ending at this breakpoint.

type is either *hyphenated* or *unhyphenated*, depending on whether this breakpoint is a *disc_node*.

total_demerits is the minimum possible sum of demerits over all lines leading from the beginning of the paragraph to this breakpoint.

The value of *link(active)* points to the first active node on a linked list of all currently active nodes. This list is in order by *line_number*, except that nodes with *line_number* > *easy_line* may be in any order relative to each other.

```

define active_node_size_normal = 3 { number of words in normal active nodes }
define fitness  $\equiv$  subtype { very_loose_fit .. tight_fit on final line for this break }
define break_node  $\equiv$  rlink { pointer to the corresponding passive node }
define line_number  $\equiv$  llink { line that begins at this breakpoint }
define total_demerits(#)  $\equiv$  mem[# + 2].int { the quantity that TeX minimizes }
define unhyphenated = 0 { the type of a normal active break node }
define hyphenated = 1 { the type of an active node that breaks at a disc_node }
define last_active  $\equiv$  active { the active list ends where it begins }

```

994. (Initialize the special list heads and constant nodes 964) + \equiv

```

type(last_active)  $\leftarrow$  hyphenated; line_number(last_active)  $\leftarrow$  max_halfword; subtype(last_active)  $\leftarrow$  0;
{ the subtype is never examined by the algorithm }

```

995. The passive node for a given breakpoint contains only four fields:

link points to the passive node created just before this one, if any, otherwise it is *null*.

cur_break points to the position of this breakpoint in the horizontal list for the paragraph being broken.

prev_break points to the passive node that should precede this one in an optimal path to this breakpoint.

serial is equal to *n* if this passive node is the *n*th one created during the current pass. (This field is used only when printing out detailed statistics about the line-breaking calculations.)

There is a global variable called *passive* that points to the most recently created passive node. Another global variable, *printed_node*, is used to help print out the paragraph when detailed information about the line-breaking computation is being displayed.

```

define passive_node_size = 2 { number of words in passive nodes }
define cur_break  $\equiv$  rlink { in passive node, points to position of this breakpoint }
define prev_break  $\equiv$  llink { points to passive node that should precede this one }
define serial  $\equiv$  info { serial number for symbolic identification }

```

(Global variables 13) + \equiv

passive: *pointer*; { most recent node on passive list }

printed_node: *pointer*; { most recent node that has been printed }

pass_number: *halfword*; { the number of passive nodes allocated on this pass }

996. The active list also contains “delta” nodes that help the algorithm compute the badness of individual lines. Such nodes appear only between two active nodes, and they have *type* = *delta_node*. If *p* and *r* are active nodes and if *q* is a delta node between them, so that *link*(*p*) = *q* and *link*(*q*) = *r*, then *q* tells the space difference between lines in the horizontal list that start after breakpoint *p* and lines that start after breakpoint *r*. In other words, if we know the length of the line that starts after *p* and ends at our current position, then the corresponding length of the line that starts after *r* is obtained by adding the amounts in node *q*. A delta node contains six scaled numbers, since it must record the net change in glue stretchability with respect to all orders of infinity. The natural width difference appears in *mem*[*q* + 1].*sc*; the stretch differences in units of pt, fil, fill, and filll appear in *mem*[*q* + 2 .. *q* + 5].*sc*; and the shrink difference appears in *mem*[*q* + 6].*sc*. The *subtype* field of a delta node is not used.

define *delta_node_size* = 9 { number of words in a delta node }

define *delta_node* = 2 { *type* field in a delta node }

997. As the algorithm runs, it maintains a set of six delta-like registers for the length of the line following the first active breakpoint to the current position in the given hlist. When it makes a pass through the active list, it also maintains a similar set of six registers for the length following the active breakpoint of current interest. A third set holds the length of an empty line (namely, the sum of `\leftskip` and `\rightskip`); and a fourth set is used to create new delta nodes.

When we pass a delta node we want to do operations like

```
for  $k \leftarrow 1$  to 6 do  $cur\_active\_width[k] \leftarrow cur\_active\_width[k] + mem[q + k].sc$ ;
```

and we want to do this without the overhead of **for** loops. The `do_all_six` macro makes such six-tuples convenient.

```
define do_all_six(#) ≡ #(1); #(2); #(3); #(4); #(5); #(6)
define do_seven_eight(#) ≡
  if pdf_adjust_spacing > 1 then
    begin #(7); #(8);
  end
define do_all_eight(#) ≡ do_all_six(#); do_seven_eight(#)
define do_one_seven_eight(#) ≡ #(1); do_seven_eight(#)
define total_font_stretch ≡ cur_active_width[7]
define total_font_shrink ≡ cur_active_width[8]
define save_active_width(#) ≡ prev_active_width[#] ← active_width[#]
define restore_active_width(#) ≡ active_width[#] ← prev_active_width[#]

⟨Global variables 13⟩ +=
active_width: array [1 .. 8] of scaled; { distance from first active node to cur_p }
cur_active_width: array [1 .. 8] of scaled; { distance from current active node }
background: array [1 .. 8] of scaled; { length of an “empty” line }
break_width: array [1 .. 8] of scaled; { length being computed after current break }
auto_breaking: boolean; { make auto_breaking accessible out of line_break }
prev_p: pointer; { make prev_p accessible out of line_break }
first_p: pointer; { to access the first node of the paragraph }
prev_char_p: pointer; { pointer to the previous char of an implicit kern }
next_char_p: pointer; { pointer to the next char of an implicit kern }
try_prev_break: boolean; { force break at the previous legal breakpoint? }
prev_legal: pointer; { the previous legal breakpoint }
prev_prev_legal: pointer; { to save prev_p corresponding to prev_legal }
prev_auto_breaking: boolean; { to save auto_breaking corresponding to prev_legal }
prev_active_width: array [1 .. 8] of scaled; { to save active_width corresponding to prev_legal }
rejected_cur_p: pointer; { the last cur_p that has been rejected }
before_rejected_cur_p: boolean; { cur_p is still before rejected_cur_p? }
max_stretch_ratio: integer; { maximal stretch ratio of expanded fonts }
max_shrink_ratio: integer; { maximal shrink ratio of expanded fonts }
cur_font_step: integer; { the current step of expanded fonts }
```

998. Let's state the principles of the delta nodes more precisely and concisely, so that the following programs will be less obscure. For each legal breakpoint p in the paragraph, we define two quantities $\alpha(p)$ and $\beta(p)$ such that the length of material in a line from breakpoint p to breakpoint q is $\gamma + \beta(q) - \alpha(p)$, for some fixed γ . Intuitively, $\alpha(p)$ and $\beta(q)$ are the total length of material from the beginning of the paragraph to a point “after” a break at p and to a point “before” a break at q ; and γ is the width of an empty line, namely the length contributed by `\leftskip` and `\rightskip`.

Suppose, for example, that the paragraph consists entirely of alternating boxes and glue skips; let the boxes have widths $x_1 \dots x_n$ and let the skips have widths $y_1 \dots y_n$, so that the paragraph can be represented by $x_1 y_1 \dots x_n y_n$. Let p_i be the legal breakpoint at y_i ; then $\alpha(p_i) = x_1 + y_1 + \dots + x_i + y_i$, and $\beta(p_i) = x_1 + y_1 + \dots + x_i$. To check this, note that the length of material from p_2 to p_5 , say, is $\gamma + x_3 + y_3 + x_4 + y_4 + x_5 = \gamma + \beta(p_5) - \alpha(p_2)$.

The quantities α , β , γ involve glue stretchability and shrinkability as well as a natural width. If we were to compute $\alpha(p)$ and $\beta(p)$ for each p , we would need multiple precision arithmetic, and the multiprecision numbers would have to be kept in the active nodes. TeX avoids this problem by working entirely with relative differences or “deltas.” Suppose, for example, that the active list contains $a_1 \delta_1 a_2 \delta_2 a_3$, where the a 's are active breakpoints and the δ 's are delta nodes. Then $\delta_1 = \alpha(a_1) - \alpha(a_2)$ and $\delta_2 = \alpha(a_2) - \alpha(a_3)$. If the line breaking algorithm is currently positioned at some other breakpoint p , the *active_width* array contains the value $\gamma + \beta(p) - \alpha(a_1)$. If we are scanning through the list of active nodes and considering a tentative line that runs from a_2 to p , say, the *cur_active_width* array will contain the value $\gamma + \beta(p) - \alpha(a_2)$. Thus, when we move from a_2 to a_3 , we want to add $\alpha(a_2) - \alpha(a_3)$ to *cur_active_width*; and this is just δ_2 , which appears in the active list between a_2 and a_3 . The *background* array contains γ . The *break_width* array will be used to calculate values of new delta nodes when the active list is being updated.

999. Glue nodes in a horizontal list that is being paragraphed are not supposed to include “infinite” shrinkability; that is why the algorithm maintains four registers for stretching but only one for shrinking. If the user tries to introduce infinite shrinkability, the shrinkability will be reset to finite and an error message will be issued. A boolean variable *no_shrink_error_yet* prevents this error message from appearing more than once per paragraph.

```

define check_shrinkage(#)  $\equiv$ 
    if (shrink_order(#)  $\neq$  normal)  $\wedge$  (shrink(#)  $\neq$  0) then
        begin #  $\leftarrow$  finite_shrink(#);
        end
 $\langle$  Global variables 13  $\rangle + \equiv$ 
no_shrink_error_yet: boolean; { have we complained about infinite shrinkage? }

```

1000. \langle Declare subprocedures for *line_break* 1000 $\rangle \equiv$
function *finite_shrink*(*p* : *pointer*): *pointer*; { recovers from infinite shrinkage }
var *q*: *pointer*; { new glue specification }
begin if *no_shrink_error_yet* **then**
 begin *no_shrink_error_yet* \leftarrow *false*;
 stat if *tracing_paragraphs* $>$ 0 **then** *end_diagnostic*(*true*);
 tats *print_err*("Infinite glue shrinkage found in a paragraph");
 help5("The paragraph just ended includes some glue that has")
 ("infinite shrinkability, e.g., `\hskip 0pt minus 1fil`."`)
 ("Such glue doesn't belong there---it allows a paragraph")
 ("of any length to fit on one line. But it's safe to proceed,")
 ("since the offensive shrinkability has been made finite."); *error*;
 stat if *tracing_paragraphs* $>$ 0 **then** *begin_diagnostic*;
 tats
 end;
 q \leftarrow *new_spec*(*p*); *shrink_order*(*q*) \leftarrow *normal*; *delete_glue_ref*(*p*); *finite_shrink* \leftarrow *q*;
end;

See also sections 1003, 1051, 1070, and 1117.

This code is used in section 989.

1001. \langle Get ready to start line breaking 990 $\rangle + \equiv$
 no_shrink_error_yet \leftarrow *true*;
 check_shrinkage(*left_skip*); *check_shrinkage*(*right_skip*);
 q \leftarrow *left_skip*; *r* \leftarrow *right_skip*; *background*[1] \leftarrow *width*(*q*) + *width*(*r*);
 background[2] \leftarrow 0; *background*[3] \leftarrow 0; *background*[4] \leftarrow 0; *background*[5] \leftarrow 0;
 background[2 + *stretch_order*(*q*)] \leftarrow *stretch*(*q*);
 background[2 + *stretch_order*(*r*)] \leftarrow *background*[2 + *stretch_order*(*r*)] + *stretch*(*r*);
 background[6] \leftarrow *shrink*(*q*) + *shrink*(*r*);
 if *pdf_adjust_spacing* $>$ 1 **then**
 begin *background*[7] \leftarrow 0; *background*[8] \leftarrow 0; *max_stretch_ratio* \leftarrow -1; *max_shrink_ratio* \leftarrow -1;
 cur_font_step \leftarrow -1; *prev_char_p* \leftarrow *null*;
 end;
 \langle Check for special treatment of last line of paragraph 1840 \rangle ;

1002. A pointer variable *cur_p* runs through the given horizontal list as we look for breakpoints. This variable is global, since it is used both by *line_break* and by its subprocedure *try_break*.

Another global variable called *threshold* is used to determine the feasibility of individual lines: Breakpoints are feasible if there is a way to reach them without creating lines whose badness exceeds *threshold*. (The badness is compared to *threshold* before penalties are added, so that penalty values do not affect the feasibility of breakpoints, except that no break is allowed when the penalty is 10000 or more.) If *threshold* is 10000 or more, all legal breaks are considered feasible, since the *badness* function specified above never returns a value greater than 10000.

Up to three passes might be made through the paragraph in an attempt to find at least one set of feasible breakpoints. On the first pass, we have *threshold* = *pretolerance* and *second_pass* = *final_pass* = *false*. If this pass fails to find a feasible solution, *threshold* is set to *tolerance*, *second_pass* is set *true*, and an attempt is made to hyphenate as many words as possible. If that fails too, we add *emergency_stretch* to the background stretchability and set *final_pass* = *true*.

\langle Global variables 13 $\rangle + \equiv$
cur_p: *pointer*; { the current breakpoint under consideration }
second_pass: *boolean*; { is this our second attempt to break this paragraph? }
final_pass: *boolean*; { is this our final attempt to break this paragraph? }
threshold: *integer*; { maximum badness on feasible lines }

1003. The heart of the line-breaking procedure is ‘*try_break*’, a subroutine that tests if the current breakpoint *cur_p* is feasible, by running through the active list to see what lines of text can be made from active nodes to *cur_p*. If feasible breaks are possible, new break nodes are created. If *cur_p* is too far from an active node, that node is deactivated.

The parameter *pi* to *try_break* is the penalty associated with a break at *cur_p*; we have *pi* = *eject_penalty* if the break is forced, and *pi* = *inf_penalty* if the break is illegal.

The other parameter, *break_type*, is set to *hyphenated* or *unhyphenated*, depending on whether or not the current break is at a *disc_node*. The end of a paragraph is also regarded as ‘*hyphenated*’; this case is distinguishable by the condition *cur_p* = *null*.

```

define copy_to_cur_active(#)  $\equiv$  cur_active_width[#]  $\leftarrow$  active_width[#]
define deactivate = 60 { go here when node r should be deactivated }
define cp_skipable(#)  $\equiv$  { skipable nodes at the margins during character protrusion }
    ( $\neg$ is_char_node(#)  $\wedge$  ((type(#) = ins_node)  $\vee$  (type(#) = mark_node)  $\vee$  (type(#) =
        adjust_node)  $\vee$  (type(#) = penalty_node)  $\vee$  ((type(#) = whatsit_node)  $\wedge$  (subtype(#)  $\neq$ 
        pdf_refximage_node)  $\wedge$  (subtype(#)  $\neq$  pdf_refxform_node))
        { reference to an image or XObject form }
     $\vee$ ((type(#) = disc_node)  $\wedge$  (pre_break(#) = null)  $\wedge$  (post_break(#) = null)  $\wedge$  (replace_count(#) = 0))
        { an empty disc_node }
     $\vee$ ((type(#) = math_node)  $\wedge$  (width(#) = 0))  $\vee$  ((type(#) = kern_node)  $\wedge$  ((width(#) =
        0)  $\vee$  (subtype(#) = normal)))  $\vee$  ((type(#) = glue_node)  $\wedge$  (glue_ptr(#) = zero_glue))  $\vee$  ((type(#) =
        hlist_node)  $\wedge$  (width(#) = 0)  $\wedge$  (height(#) = 0)  $\wedge$  (depth(#) = 0)  $\wedge$  (list_ptr(#) = null)))

<Declare subprocedures for line_break 1000> +=
procedure push_node(p : pointer);
    begin if hlist_stack_level > max_hlist_stack then pdf_error("push_node", "stack_overflow");
    hlist_stack[hlist_stack_level]  $\leftarrow$  p; hlist_stack_level  $\leftarrow$  hlist_stack_level + 1;
    end;
function pop_node: pointer;
    begin hlist_stack_level  $\leftarrow$  hlist_stack_level - 1;
    if hlist_stack_level < 0 then { would point to some bug }
        pdf_error("pop_node", "stack_underflow_(internal_error)");
    pop_node  $\leftarrow$  hlist_stack[hlist_stack_level];
    end;
function find_protchar_left(l : pointer; d : boolean): pointer;
    { searches left to right from list head l, returns 1st non-skipable item }
    var t: pointer; run: boolean;
    begin if (link(l)  $\neq$  null)  $\wedge$  (type(l) = hlist_node)  $\wedge$  (width(l) = 0)  $\wedge$  (height(l) = 0)  $\wedge$  (depth(l) =
        0)  $\wedge$  (list_ptr(l) = null) then l  $\leftarrow$  link(l) { for paragraph start with \parindent = 0pt }
    else if d then
        while (link(l)  $\neq$  null)  $\wedge$  ( $\neg$ (is_char_node(l)  $\vee$  non_discardable(l))) do l  $\leftarrow$  link(l);
        { std. discardables at line break, TEXbook, p 95 }
    hlist_stack_level  $\leftarrow$  0; run  $\leftarrow$  true;
    repeat t  $\leftarrow$  l;
        while run  $\wedge$  (type(l) = hlist_node)  $\wedge$  (list_ptr(l)  $\neq$  null) do
            begin push_node(l); l  $\leftarrow$  list_ptr(l);
            end;
        while run  $\wedge$  cp_skipable(l) do
            begin while (link(l) = null)  $\wedge$  (hlist_stack_level > 0) do
                begin l  $\leftarrow$  pop_node; { don't visit this node again }
                end;
            if link(l)  $\neq$  null then l  $\leftarrow$  link(l)
            else if hlist_stack_level = 0 then run  $\leftarrow$  false
            end;
    end;

```

```

until  $t = l$ ;
 $find\_protchar\_left \leftarrow l$ ;
end;
function  $find\_protchar\_right(l, r : pointer) : pointer$ ;
    { searches right to left from list tail  $r$  to head  $l$ , returns 1st non-skipable item }
var  $t : pointer$ ;  $run : boolean$ ;
begin  $find\_protchar\_right \leftarrow null$ ;
if  $r = null$  then return;
 $hlist\_stack\_level \leftarrow 0$ ;  $run \leftarrow true$ ;
repeat  $t \leftarrow r$ ;
    while  $run \wedge (type(r) = hlist\_node) \wedge (list\_ptr(r) \neq null)$  do
        begin  $push\_node(l)$ ;  $push\_node(r)$ ;  $l \leftarrow list\_ptr(r)$ ;  $r \leftarrow l$ ;
        while  $link(r) \neq null$  do  $r \leftarrow link(r)$ ;
        end;
    while  $run \wedge cp\_skipable(r)$  do
        begin while  $(r = l) \wedge (hlist\_stack\_level > 0)$  do
            begin  $r \leftarrow pop\_node$ ; { don't visit this node again }
             $l \leftarrow pop\_node$ ;
            end;
        if  $(r \neq l) \wedge (r \neq null)$  then  $r \leftarrow prev\_rightmost(l, r)$ 
        else if  $(r = l) \wedge (hlist\_stack\_level = 0)$  then  $run \leftarrow false$ 
        end;
    until  $t = r$ ;
     $find\_protchar\_right \leftarrow r$ ;
end;
function  $total\_pw(q, p : pointer) : scaled$ ;
    { returns the total width of character protrusion of a line;  $cur\_break(break\_node(q))$  and  $p$  is the
    leftmost resp. rightmost node in the horizontal list representing the actual line }
var  $l, r : pointer$ ;  $n : integer$ ;
begin if  $break\_node(q) = null$  then  $l \leftarrow first\_p$ 
else  $l \leftarrow cur\_break(break\_node(q))$ ;
 $r \leftarrow prev\_rightmost(prev\_p, p)$ ; { get  $link(r) = p$  }
    { let's look at the right margin first }
@{ $short\_display\_n(r, 2)$ ;  $print("&")$ ;  $short\_display\_n(p, 2)$ ;  $print\_ln$ ; @}
    if  $(p \neq null) \wedge (type(p) = disc\_node) \wedge (pre\_break(p) \neq null)$  then
        { a  $disc\_node$  with non-empty  $pre\_break$ , protrude the last char of  $pre\_break$  }
        begin  $r \leftarrow pre\_break(p)$ ;
        while  $link(r) \neq null$  do  $r \leftarrow link(r)$ ;
        end
    else  $r \leftarrow find\_protchar\_right(l, r)$ ; { now the left margin }
@{ $short\_display\_n(l, 2)$ ;  $print\_ln$ ;  $breadth\_max \leftarrow 10$ ;  $depth\_threshold \leftarrow 2$ ;  $show\_node\_list(l)$ ;  $print\_ln$ ;
@}
    if  $(l \neq null) \wedge (type(l) = disc\_node)$  then
        begin if  $post\_break(l) \neq null$  then
            begin  $l \leftarrow post\_break(l)$ ; { protrude the first char }
            goto done;
            end
        else { discard  $replace\_count(l)$  nodes }
        begin  $n \leftarrow replace\_count(l)$ ;  $l \leftarrow link(l)$ ;
        while  $n > 0$  do
            begin if  $link(l) \neq null$  then  $l \leftarrow link(l)$ ;
             $decr(n)$ ;

```

```

    end;
  end;
end;
  l ← find_protchar_left(l, true);
done: total_pw ← left_pw(l) + right_pw(r);
end;
procedure try_break(pi : integer; break_type : small_number);
  label exit, done, done1, continue, deactivate, found, not_found;
  var r: pointer; { runs through the active list }
      margin_kern_stretch: scaled; margin_kern_shrink: scaled; lp, rp, cp: pointer; prev_r: pointer;
      { stays a step behind r }
      old_l: halfword; { maximum line number in current equivalence class of lines }
      no_break_yet: boolean; { have we found a feasible break at cur_p? }
      ⟨Other local variables for try_break 1004⟩
  begin ⟨Make sure that pi is in the proper range 1005⟩;
  no_break_yet ← true; prev_r ← active; old_l ← 0; do_all_eight(copy_to_cur_active);
  loop begin continue: r ← link(prev_r); ⟨If node r is of type delta_node, update cur_active_width, set
      prev_r and prev_prev_r, then goto continue 1006⟩;
    ⟨If a line number class has ended, create new active nodes for the best feasible breaks in that class;
      then return if r = last_active, otherwise compute the new line_width 1009⟩;
    ⟨Consider the demerits for a line from r to cur_p; deactivate node r if it should no longer be active;
      then goto continue if a line from r to cur_p is infeasible, otherwise record a new feasible
      break 1025⟩;
  end;
exit: stat ⟨Update the value of printed_node for symbolic displays 1032⟩ tats
end;

```

1004. ⟨Other local variables for try_break 1004⟩ ≡

```

prev_prev_r: pointer; { a step behind prev_r, if type(prev_r) = delta_node }
s: pointer; { runs through nodes ahead of cur_p }
q: pointer; { points to a new node being created }
v: pointer; { points to a glue specification or a node ahead of cur_p }
t: integer; { node count, if cur_p is a discretionary node }
f: internal_font_number; { used in character width calculation }
l: halfword; { line number of current active node }
node_r_stays_active: boolean; { should node r remain in the active list? }
line_width: scaled; { the current line will be justified to this width }
fit_class: very_loose_fit .. tight_fit; { possible fitness class of test line }
b: halfword; { badness of test line }
d: integer; { demerits of test line }
artificial_demerits: boolean; { has d been forced to zero? }
save_link: pointer; { temporarily holds value of link(cur_p) }
shortfall: scaled; { used in badness calculations }

```

See also section 1841.

This code is used in section 1003.

1005. ⟨Make sure that pi is in the proper range 1005⟩ ≡

```

if abs(pi) ≥ inf_penalty then
  if pi > 0 then return { this breakpoint is inhibited by infinite penalty }
  else pi ← eject_penalty { this breakpoint will be forced }

```

This code is used in section 1003.

1006. The following code uses the fact that $\text{type}(\text{last_active}) \neq \text{delta_node}$.

```
define update_width(#)  $\equiv$  cur_active_width[#]  $\leftarrow$  cur_active_width[#] + mem[r + #].sc
⟨If node r is of type delta_node, update cur_active_width, set prev_r and prev_prev_r, then goto
  continue 1006⟩  $\equiv$ 
if type(r) = delta_node then
  begin do_all_eight(update_width); prev_prev_r  $\leftarrow$  prev_r; prev_r  $\leftarrow$  r; goto continue;
end
```

This code is used in section 1003.

1007. As we consider various ways to end a line at *cur_p*, in a given line number class, we keep track of the best total demerits known, in an array with one entry for each of the fitness classifications. For example, *minimal_demerits*[*tight_fit*] contains the fewest total demerits of feasible line breaks ending at *cur_p* with a *tight_fit* line; *best_place*[*tight_fit*] points to the passive node for the break before *cur_p* that achieves such an optimum; and *best_pl_line*[*tight_fit*] is the *line_number* field in the active node corresponding to *best_place*[*tight_fit*]. When no feasible break sequence is known, the *minimal_demerits* entries will be equal to *awful_bad*, which is $2^{30} - 1$. Another variable, *minimum_demerits*, keeps track of the smallest value in the *minimal_demerits* array.

```
define awful_bad  $\equiv$  '7777777777' { more than a billion demerits }
⟨Global variables 13⟩ + $\equiv$ 
minimal_demerits: array [very_loose_fit .. tight_fit] of integer;
  { best total demerits known for current line class and position, given the fitness }
minimum_demerits: integer; { best total demerits known for current line class and position }
best_place: array [very_loose_fit .. tight_fit] of pointer; { how to achieve minimal_demerits }
best_pl_line: array [very_loose_fit .. tight_fit] of halfword; { corresponding line number }
```

1008. ⟨Get ready to start line breaking 990⟩ + \equiv

```
minimum_demerits  $\leftarrow$  awful_bad; minimal_demerits[tight_fit]  $\leftarrow$  awful_bad;
minimal_demerits[decent_fit]  $\leftarrow$  awful_bad; minimal_demerits[loose_fit]  $\leftarrow$  awful_bad;
minimal_demerits[very_loose_fit]  $\leftarrow$  awful_bad;
```

1009. The first part of the following code is part of TeX's inner loop, so we don't want to waste any time. The current active node, namely node *r*, contains the line number that will be considered next. At the end of the list we have arranged the data structure so that $r = \text{last_active}$ and $\text{line_number}(\text{last_active}) > \text{old_l}$.

```
⟨If a line number class has ended, create new active nodes for the best feasible breaks in that class; then
  return if  $r = \text{last\_active}$ , otherwise compute the new line_width 1009⟩  $\equiv$ 
begin l  $\leftarrow$  line_number(r);
if l > old_l then
  begin { now we are no longer in the inner loop }
  if (minimum_demerits < awful_bad)  $\wedge$  ((old_l  $\neq$  easy_line)  $\vee$  ( $r = \text{last\_active}$ )) then
    ⟨Create new active nodes for the best feasible breaks just found 1010⟩;
  if  $r = \text{last\_active}$  then return;
  ⟨Compute the new line width 1024⟩;
  end;
end
```

This code is used in section 1003.

1010. It is not necessary to create new active nodes having *minimal_demerits* greater than *minimum_demerits* + $\text{abs}(\text{adj_demerits})$, since such active nodes will never be chosen in the final paragraph breaks. This observation allows us to omit a substantial number of feasible breakpoints from further consideration.

```

⟨Create new active nodes for the best feasible breaks just found 1010⟩ ≡
  begin if no_break_yet then ⟨Compute the values of break_width 1011⟩;
  ⟨Insert a delta node to prepare for breaks at cur_p 1017⟩;
  if abs(adj_demerits) ≥ awful_bad - minimum_demerits then minimum_demerits ← awful_bad - 1
  else minimum_demerits ← minimum_demerits + abs(adj_demerits);
  for fit_class ← very_loose_fit to tight_fit do
    begin if minimal_demerits[fit_class] ≤ minimum_demerits then
      ⟨Insert a new active node from best_place[fit_class] to cur_p 1019⟩;
      minimal_demerits[fit_class] ← awful_bad;
    end;
  minimum_demerits ← awful_bad; ⟨Insert a delta node to prepare for the next active node 1018⟩;
end

```

This code is used in section 1009.

1011. When we insert a new active node for a break at *cur_p*, suppose this new node is to be placed just before active node *a*; then we essentially want to insert ‘ δ *cur_p* δ' ’ before *a*, where $\delta = \alpha(a) - \alpha(\text{cur_p})$ and $\delta' = \alpha(\text{cur_p}) - \alpha(a)$ in the notation explained above. The *cur_active_width* array now holds $\gamma + \beta(\text{cur_p}) - \alpha(a)$; so δ can be obtained by subtracting *cur_active_width* from the quantity $\gamma + \beta(\text{cur_p}) - \alpha(\text{cur_p})$. The latter quantity can be regarded as the length of a line “from *cur_p* to *cur_p*”; we call it the *break_width* at *cur_p*.

The *break_width* is usually negative, since it consists of the background (which is normally zero) minus the width of nodes following *cur_p* that are eliminated after a break. If, for example, node *cur_p* is a glue node, the width of this glue is subtracted from the background; and we also look ahead to eliminate all subsequent glue and penalty and kern and math nodes, subtracting their widths as well.

Kern nodes do not disappear at a line break unless they are *explicit*.

define *set_break_width_to_background*(#) ≡ *break_width*[#] ← *background*[#]

```

⟨Compute the values of break_width 1011⟩ ≡
  begin no_break_yet ← false; do_all_eight(set_break_width_to_background); s ← cur_p;
  if break_type > unhyphenated then
    if cur_p ≠ null then ⟨Compute the discretionary break_width values 1014⟩;
  while s ≠ null do
    begin if is_char_node(s) then goto done;
    case type(s) of
      glue_node: ⟨Subtract glue from break_width 1012⟩;
      penalty_node: do_nothing;
      math_node: break_width[1] ← break_width[1] - width(s);
      kern_node: if subtype(s) ≠ explicit then goto done
        else break_width[1] ← break_width[1] - width(s);
    othercases goto done
    endcases;
    s ← link(s);
  end;
done: end

```

This code is used in section 1010.

1012. \langle Subtract glue from *break_width* **1012** $\rangle \equiv$

```
begin  $v \leftarrow glue\_ptr(s)$ ;  $break\_width[1] \leftarrow break\_width[1] - width(v)$ ;
 $break\_width[2 + stretch\_order(v)] \leftarrow break\_width[2 + stretch\_order(v)] - stretch(v)$ ;
 $break\_width[6] \leftarrow break\_width[6] - shrink(v)$ ;
end
```

This code is used in section **1011**.

1013. When *cur_p* is a discretionary break, the length of a line “from *cur_p* to *cur_p*” has to be defined properly so that the other calculations work out. Suppose that the pre-break text at *cur_p* has length l_0 , the post-break text has length l_1 , and the replacement text has length l . Suppose also that q is the node following the replacement text. Then length of a line from *cur_p* to q will be computed as $\gamma + \beta(q) - \alpha(cur_p)$, where $\beta(q) = \beta(cur_p) - l_0 + l$. The actual length will be the background plus l_1 , so the length from *cur_p* to *cur_p* should be $\gamma + l_0 + l_1 - l$. If the post-break text of the discretionary is empty, a break may also discard q ; in that unusual case we subtract the length of q and any other nodes that will be discarded after the discretionary break.

The value of l_0 need not be computed, since *line_break* will put it into the global variable *disc_width* before calling *try_break*.

```
define  $reset\_disc\_width(\#) \equiv disc\_width[\#] \leftarrow 0$ 
define  $add\_disc\_width\_to\_break\_width(\#) \equiv break\_width[\#] \leftarrow break\_width[\#] + disc\_width[\#]$ 
define  $add\_disc\_width\_to\_active\_width(\#) \equiv active\_width[\#] \leftarrow active\_width[\#] + disc\_width[\#]$ 
define  $sub\_disc\_width\_from\_active\_width(\#) \equiv active\_width[\#] \leftarrow active\_width[\#] - disc\_width[\#]$ 
define  $add\_char\_stretch\_end(\#) \equiv char\_stretch(f, \#)$ 
define  $add\_char\_stretch(\#) \equiv \# \leftarrow \# + add\_char\_stretch\_end$ 
define  $add\_char\_shrink\_end(\#) \equiv char\_shrink(f, \#)$ 
define  $add\_char\_shrink(\#) \equiv \# \leftarrow \# + add\_char\_shrink\_end$ 
define  $sub\_char\_stretch\_end(\#) \equiv char\_stretch(f, \#)$ 
define  $sub\_char\_stretch(\#) \equiv \# \leftarrow \# - sub\_char\_stretch\_end$ 
define  $sub\_char\_shrink\_end(\#) \equiv char\_shrink(f, \#)$ 
define  $sub\_char\_shrink(\#) \equiv \# \leftarrow \# - sub\_char\_shrink\_end$ 
define  $add\_kern\_stretch\_end(\#) \equiv kern\_stretch(\#)$ 
define  $add\_kern\_stretch(\#) \equiv \# \leftarrow \# + add\_kern\_stretch\_end$ 
define  $add\_kern\_shrink\_end(\#) \equiv kern\_shrink(\#)$ 
define  $add\_kern\_shrink(\#) \equiv \# \leftarrow \# + add\_kern\_shrink\_end$ 
define  $sub\_kern\_stretch\_end(\#) \equiv kern\_stretch(\#)$ 
define  $sub\_kern\_stretch(\#) \equiv \# \leftarrow \# - sub\_kern\_stretch\_end$ 
define  $sub\_kern\_shrink\_end(\#) \equiv kern\_shrink(\#)$ 
define  $sub\_kern\_shrink(\#) \equiv \# \leftarrow \# - sub\_kern\_shrink\_end$ 
```

\langle Global variables **13** $\rangle + \equiv$

disc_width: **array** [1 .. 8] **of** *scaled*; { the length of discretionary material preceding a break }

1014. \langle Compute the discretionary *break_width* values [1014](#) $\rangle \equiv$

```

begin  $t \leftarrow \text{replace\_count}(\text{cur\_p}); v \leftarrow \text{cur\_p}; s \leftarrow \text{post\_break}(\text{cur\_p});$ 
while  $t > 0$  do
  begin  $\text{decr}(t); v \leftarrow \text{link}(v);$   $\langle$  Subtract the width of node  $v$  from break_width 1015  $\rangle;$ 
  end;
while  $s \neq \text{null}$  do
  begin  $\langle$  Add the width of node  $s$  to break_width 1016  $\rangle;$ 
   $s \leftarrow \text{link}(s);$ 
  end;
 $\text{do\_one\_seven\_eight}(\text{add\_disc\_width\_to\_break\_width});$ 
if  $\text{post\_break}(\text{cur\_p}) = \text{null}$  then  $s \leftarrow \text{link}(v);$  { nodes may be discardable after the break }
end

```

This code is used in section [1011](#).

1015. Replacement texts and discretionary texts are supposed to contain only character nodes, kern nodes, ligature nodes, and box or rule nodes.

\langle Subtract the width of node v from *break_width* [1015](#) $\rangle \equiv$

```

if  $\text{is\_char\_node}(v)$  then
  begin  $f \leftarrow \text{font}(v); \text{break\_width}[1] \leftarrow \text{break\_width}[1] - \text{char\_width}(f)(\text{char\_info}(f)(\text{character}(v)));$ 
  if  $(\text{pdf\_adjust\_spacing} > 1) \wedge \text{check\_expand\_pars}(f)$  then
    begin  $\text{prev\_char\_p} \leftarrow v; \text{sub\_char\_stretch}(\text{break\_width}[7])(\text{character}(v));$ 
     $\text{sub\_char\_shrink}(\text{break\_width}[8])(\text{character}(v));$ 
    end;
  end
else case  $\text{type}(v)$  of
   $\text{ligature\_node}$ : begin  $f \leftarrow \text{font}(\text{lig\_char}(v));$ 
   $\text{break\_width}[1] \leftarrow \text{break\_width}[1] - \text{char\_width}(f)(\text{char\_info}(f)(\text{character}(\text{lig\_char}(v))));$ 
  if  $(\text{pdf\_adjust\_spacing} > 1) \wedge \text{check\_expand\_pars}(f)$  then
    begin  $\text{prev\_char\_p} \leftarrow v; \text{sub\_char\_stretch}(\text{break\_width}[7])(\text{character}(\text{lig\_char}(v)));$ 
     $\text{sub\_char\_shrink}(\text{break\_width}[8])(\text{character}(\text{lig\_char}(v)));$ 
    end;
  end;
   $\text{hlist\_node}, \text{vlist\_node}, \text{rule\_node}, \text{kern\_node}$ : begin  $\text{break\_width}[1] \leftarrow \text{break\_width}[1] - \text{width}(v);$ 
  if  $(\text{type}(v) = \text{kern\_node}) \wedge (\text{pdf\_adjust\_spacing} > 1) \wedge (\text{subtype}(v) = \text{normal})$  then
    begin  $\text{sub\_kern\_stretch}(\text{break\_width}[7])(v); \text{sub\_kern\_shrink}(\text{break\_width}[8])(v);$ 
    end;
  end;
othercases  $\text{confusion}(\text{"disc1"})$ 
endcases

```

This code is used in section [1014](#).

```

1016.  ⟨ Add the width of node s to break_width 1016 ⟩ ≡
  if is_char_node(s) then
    begin f ← font(s); break_width[1] ← break_width[1] + char_width(f)(char_info(f)(character(s)));
    if (pdf_adjust_spacing > 1) ∧ check_expand_pars(f) then
      begin prev_char_p ← s; add_char_stretch(break_width[7])(character(s));
      add_char_shrink(break_width[8])(character(s));
      end;
    end
  else case type(s) of
    ligature_node: begin f ← font(lig_char(s));
      break_width[1] ← break_width[1] + char_width(f)(char_info(f)(character(lig_char(s))));
      if (pdf_adjust_spacing > 1) ∧ check_expand_pars(f) then
        begin prev_char_p ← s; add_char_stretch(break_width[7])(character(lig_char(s)));
        add_char_shrink(break_width[8])(character(lig_char(s)));
        end;
      end;
    hlist_node, vlist_node, rule_node, kern_node: begin break_width[1] ← break_width[1] + width(s);
      if (type(s) = kern_node) ∧ (pdf_adjust_spacing > 1) ∧ (subtype(s) = normal) then
        begin add_kern_stretch(break_width[7])(s); add_kern_shrink(break_width[8])(s);
        end;
      end;
    othercases confusion("disc2")
  endcases

```

This code is used in section 1014.

1017. We use the fact that *type*(*active*) ≠ *delta_node*.

```

define convert_to_break_width(#) ≡ mem[prev_r + #].sc ←
  mem[prev_r + #].sc − cur_active_width[#] + break_width[#]
define store_break_width(#) ≡ active_width[#] ← break_width[#]
define new_delta_to_break_width(#) ≡ mem[q + #].sc ← break_width[#] − cur_active_width[#]
⟨ Insert a delta node to prepare for breaks at cur_p 1017 ⟩ ≡
if type(prev_r) = delta_node then { modify an existing delta node }
  begin do_all_eight(convert_to_break_width);
  end
else if prev_r = active then { no delta node needed at the beginning }
  begin do_all_eight(store_break_width);
  end
else begin q ← get_node(delta_node_size); link(q) ← r; type(q) ← delta_node;
  subtype(q) ← 0; { the subtype is not used }
  do_all_eight(new_delta_to_break_width); link(prev_r) ← q; prev_prev_r ← prev_r; prev_r ← q;
end

```

This code is used in section 1010.

1018. When the following code is performed, we will have just inserted at least one active node before r , so $type(prev_r) \neq delta_node$.

```
define new_delta_from_break_width( $\#$ )  $\equiv mem[q + \#].sc \leftarrow cur\_active\_width[\#] - break\_width[\#]$ 
 $\langle$  Insert a delta node to prepare for the next active node 1018  $\rangle \equiv$ 
if  $r \neq last\_active$  then
  begin  $q \leftarrow get\_node(delta\_node\_size)$ ;  $link(q) \leftarrow r$ ;  $type(q) \leftarrow delta\_node$ ;
   $subtype(q) \leftarrow 0$ ; { the subtype is not used }
   $do\_all\_eight(new\_delta\_from\_break\_width)$ ;  $link(prev\_r) \leftarrow q$ ;  $prev\_prev\_r \leftarrow prev\_r$ ;  $prev\_r \leftarrow q$ ;
end
```

This code is used in section 1010.

1019. When we create an active node, we also create the corresponding passive node.

```
 $\langle$  Insert a new active node from  $best\_place[fit\_class]$  to  $cur\_p$  1019  $\rangle \equiv$ 
begin  $q \leftarrow get\_node(passive\_node\_size)$ ;  $link(q) \leftarrow passive$ ;  $passive \leftarrow q$ ;  $cur\_break(q) \leftarrow cur\_p$ ;
stat  $incr(pass\_number)$ ;  $serial(q) \leftarrow pass\_number$ ; tats
 $prev\_break(q) \leftarrow best\_place[fit\_class]$ ;
 $q \leftarrow get\_node(active\_node\_size)$ ;  $break\_node(q) \leftarrow passive$ ;  $line\_number(q) \leftarrow best\_pl\_line[fit\_class] + 1$ ;
 $fitness(q) \leftarrow fit\_class$ ;  $type(q) \leftarrow break\_type$ ;  $total\_demerits(q) \leftarrow minimal\_demerits[fit\_class]$ ;
if  $do\_last\_line\_fit$  then  $\langle$  Store additional data in the new active node 1848  $\rangle$ ;
 $link(q) \leftarrow r$ ;  $link(prev\_r) \leftarrow q$ ;  $prev\_r \leftarrow q$ ;
stat if  $tracing\_paragraphs > 0$  then  $\langle$  Print a symbolic description of the new break node 1020  $\rangle$ ;
tats
end
```

This code is used in section 1010.

```
1020.  $\langle$  Print a symbolic description of the new break node 1020  $\rangle \equiv$ 
begin  $print\_nl("@@")$ ;  $print\_int(serial(passive))$ ;  $print(": \_line\_")$ ;  $print\_int(line\_number(q) - 1)$ ;
 $print\_char(".")$ ;  $print\_int(fit\_class)$ ;
if  $break\_type = hyphenated$  then  $print\_char("-")$ ;
 $print("\_t=")$ ;  $print\_int(total\_demerits(q))$ ;
if  $do\_last\_line\_fit$  then  $\langle$  Print additional data in the new active node 1849  $\rangle$ ;
 $print("\_ \rightarrow \_ @@")$ ;
if  $prev\_break(passive) = null$  then  $print\_char("0")$ 
else  $print\_int(serial(prev\_break(passive)))$ ;
end
```

This code is used in section 1019.

1021. The length of lines depends on whether the user has specified `\parshape` or `\hangindent`. If `par_shape_ptr` is not null, it points to a $(2n + 1)$ -word record in *mem*, where the *info* in the first word contains the value of n , and the other $2n$ words contain the left margins and line lengths for the first n lines of the paragraph; the specifications for line n apply to all subsequent lines. If `par_shape_ptr = null`, the shape of the paragraph depends on the value of $n = \text{hang_after}$; if $n \geq 0$, hanging indentation takes place on lines $n + 1, n + 2, \dots$, otherwise it takes place on lines $1, \dots, |n|$. When hanging indentation is active, the left margin is *hang_indent*, if *hang_indent* ≥ 0 , else it is 0; the line length is *hsize* - $|\text{hang_indent}|$. The normal setting is `par_shape_ptr = null`, `hang_after = 1`, and `hang_indent = 0`. Note that if *hang_indent* = 0, the value of *hang_after* is irrelevant.

\langle Global variables 13 $\rangle + \equiv$
easy_line: halfword; { line numbers $> \text{easy_line}$ are equivalent in break nodes }
last_special_line: halfword; { line numbers $> \text{last_special_line}$ all have the same width }
first_width: scaled; { the width of all lines $\leq \text{last_special_line}$, if no `\parshape` has been specified }
second_width: scaled; { the width of all lines $> \text{last_special_line}$ }
first_indent: scaled; { left margin to go with *first_width* }
second_indent: scaled; { left margin to go with *second_width* }

1022. We compute the values of *easy_line* and the other local variables relating to line length when the *line_break* procedure is initializing itself.

\langle Get ready to start line breaking 990 $\rangle + \equiv$
if *par_shape_ptr* = null **then**
 if *hang_indent* = 0 **then**
 begin *last_special_line* \leftarrow 0; *second_width* \leftarrow *hsize*; *second_indent* \leftarrow 0;
 end
 else \langle Set line length parameters in preparation for hanging indentation 1023 \rangle
else begin *last_special_line* \leftarrow *info*(*par_shape_ptr*) - 1;
 second_width \leftarrow *mem*[*par_shape_ptr* + 2 * (*last_special_line* + 1)].*sc*;
 second_indent \leftarrow *mem*[*par_shape_ptr* + 2 * *last_special_line* + 1].*sc*;
 end;
if *looseness* = 0 **then** *easy_line* \leftarrow *last_special_line*
else *easy_line* \leftarrow *max_halfword*

1023. \langle Set line length parameters in preparation for hanging indentation 1023 $\rangle \equiv$
begin *last_special_line* \leftarrow *abs*(*hang_after*);
if *hang_after* < 0 **then**
 begin *first_width* \leftarrow *hsize* - *abs*(*hang_indent*);
 if *hang_indent* \geq 0 **then** *first_indent* \leftarrow *hang_indent*
 else *first_indent* \leftarrow 0;
 second_width \leftarrow *hsize*; *second_indent* \leftarrow 0;
 end
else begin *first_width* \leftarrow *hsize*; *first_indent* \leftarrow 0; *second_width* \leftarrow *hsize* - *abs*(*hang_indent*);
 if *hang_indent* \geq 0 **then** *second_indent* \leftarrow *hang_indent*
 else *second_indent* \leftarrow 0;
 end;
end

This code is used in section 1022.

1024. When we come to the following code, we have just encountered the first active node r whose *line_number* field contains l . Thus we want to compute the length of the l th line of the current paragraph. Furthermore, we want to set *old_l* to the last number in the class of line numbers equivalent to l .

⟨Compute the new line width 1024⟩ \equiv

```

if  $l > \text{easy\_line}$  then
  begin  $\text{line\_width} \leftarrow \text{second\_width}$ ;  $\text{old\_l} \leftarrow \text{max\_halfword} - 1$ ;
  end
else begin  $\text{old\_l} \leftarrow l$ ;
  if  $l > \text{last\_special\_line}$  then  $\text{line\_width} \leftarrow \text{second\_width}$ 
  else if  $\text{par\_shape\_ptr} = \text{null}$  then  $\text{line\_width} \leftarrow \text{first\_width}$ 
    else  $\text{line\_width} \leftarrow \text{mem}[\text{par\_shape\_ptr} + 2 * l].\text{sc}$ ;
  end

```

This code is used in section 1009.

1025. The remaining part of *try_break* deals with the calculation of demerits for a break from r to cur_p .

The first thing to do is calculate the badness, b . This value will always be between zero and $inf_bad + 1$; the latter value occurs only in the case of lines from r to cur_p that cannot shrink enough to fit the necessary width. In such cases, node r will be deactivated. We also deactivate node r when a break at cur_p is forced, since future breaks must go through a forced break.

```

⟨ Consider the demerits for a line from  $r$  to  $cur\_p$ ; deactivate node  $r$  if it should no longer be active; then
  goto continue if a line from  $r$  to  $cur\_p$  is infeasible, otherwise record a new feasible break 1025 ⟩ ≡
begin artificial_demerits  $\leftarrow$  false;
shortfall  $\leftarrow$  line_width  $-$  cur_active_width[1]; { we're this much too short }
@{
  if pdf_output  $>$  2 then
    begin print_ln;
    if ( $r \neq null$ )  $\wedge$  (break_node( $r$ )  $\neq null$ ) then short_display_n(cur_break(break_node( $r$ )), 5);
    print_ln; short_display_n( $cur\_p$ , 5); print_ln;
    end;
  @}
  if pdf_protrude_chars  $>$  1 then shortfall  $\leftarrow$  shortfall + total_pw( $r$ ,  $cur\_p$ );
if (pdf_adjust_spacing  $>$  1)  $\wedge$  (shortfall  $\neq$  0) then
  begin margin_kern_stretch  $\leftarrow$  0; margin_kern_shrink  $\leftarrow$  0;
  if pdf_protrude_chars  $>$  1 then ⟨ Calculate variations of marginal kerns 820 ⟩;
  if (shortfall  $>$  0)  $\wedge$  ((total_font_stretch + margin_kern_stretch)  $>$  0) then
    begin if (total_font_stretch + margin_kern_stretch)  $>$  shortfall then
      shortfall  $\leftarrow$  ((total_font_stretch + margin_kern_stretch) div (max_stretch_ratio div cur_font_step)) div 2
    else shortfall  $\leftarrow$  shortfall  $-$  (total_font_stretch + margin_kern_stretch);
    end
  else if (shortfall  $<$  0)  $\wedge$  ((total_font_shrink + margin_kern_shrink)  $>$  0) then
    begin if (total_font_shrink + margin_kern_shrink)  $>$   $-$ shortfall then shortfall  $\leftarrow$ 
       $-$ ((total_font_shrink + margin_kern_shrink) div (max_shrink_ratio div cur_font_step)) div 2
    else shortfall  $\leftarrow$  shortfall + (total_font_shrink + margin_kern_shrink);
    end;
  end;
  if shortfall  $>$  0 then
    ⟨ Set the value of  $b$  to the badness for stretching the line, and compute the corresponding fit_class 1026 ⟩
  else ⟨ Set the value of  $b$  to the badness for shrinking the line, and compute the corresponding
    fit_class 1027 ⟩;
  if do_last_line_fit then ⟨ Adjust the additional data for last line 1846 ⟩;
found: if ( $b > inf\_bad$ )  $\vee$  ( $pi = eject\_penalty$ ) then ⟨ Prepare to deactivate node  $r$ , and goto deactivate
    unless there is a reason to consider lines of text from  $r$  to  $cur\_p$  1028 ⟩
  else begin prev_r  $\leftarrow$   $r$ ;
    if  $b > threshold$  then goto continue;
    node_r_stays_active  $\leftarrow$  true;
    end;
  ⟨ Record a new feasible break 1029 ⟩;
  if node_r_stays_active then goto continue; { prev_r has been set to  $r$  }
deactivate: ⟨ Deactivate node  $r$  1034 ⟩;
end

```

This code is used in section 1003.

1026. When a line must stretch, the available stretchability can be found in the subarray *cur_active_width*[2 .. 5], in units of points, fil, fill, and filll.

The present section is part of TeX's inner loop, and it is most often performed when the badness is infinite; therefore it is worth while to make a quick test for large width excess and small stretchability, before calling the *badness* subroutine.

```

⟨Set the value of b to the badness for stretching the line, and compute the corresponding fit_class 1026⟩ ≡
  if (cur_active_width[3] ≠ 0) ∨ (cur_active_width[4] ≠ 0) ∨ (cur_active_width[5] ≠ 0) then
    begin if do_last_line_fit then
      begin if cur_p = null then { the last line of a paragraph }
        ⟨Perform computations for last line and goto found 1843⟩;
        shortfall ← 0;
      end;
      b ← 0; fit_class ← decent_fit; { infinite stretch }
    end
  else begin if shortfall > 7230584 then
    if cur_active_width[2] < 1663497 then
      begin b ← inf_bad; fit_class ← very_loose_fit; goto done1;
      end;
      b ← badness(shortfall, cur_active_width[2]);
    if b > 12 then
      if b > 99 then fit_class ← very_loose_fit
      else fit_class ← loose_fit
    else fit_class ← decent_fit;
    done1: end

```

This code is used in section 1025.

1027. Shrinkability is never infinite in a paragraph; we can shrink the line from *r* to *cur_p* by at most *cur_active_width*[6].

```

⟨Set the value of b to the badness for shrinking the line, and compute the corresponding fit_class 1027⟩ ≡
  begin if −shortfall > cur_active_width[6] then b ← inf_bad + 1
  else b ← badness(−shortfall, cur_active_width[6]);
  if b > 12 then fit_class ← tight_fit else fit_class ← decent_fit;
  end

```

This code is used in section 1025.

1028. During the final pass, we dare not lose all active nodes, lest we lose touch with the line breaks already found. The code shown here makes sure that such a catastrophe does not happen, by permitting overfull boxes as a last resort. This particular part of TeX was a source of several subtle bugs before the correct program logic was finally discovered; readers who seek to “improve” TeX should therefore think thrice before daring to make any changes here.

```

⟨Prepare to deactivate node r, and goto deactivate unless there is a reason to consider lines of text from r to cur_p 1028⟩ ≡
  begin if final_pass ∧ (minimum_demerits = awful_bad) ∧ (link(r) = last_active) ∧ (prev_r = active) then
    artificial_demerits ← true { set demerits zero, this break is forced }
  else if b > threshold then goto deactivate;
  node_r_stays_active ← false;
  end

```

This code is used in section 1025.

1029. When we get to this part of the code, the line from r to cur_p is feasible, its badness is b , and its fitness classification is fit_class . We don't want to make an active node for this break yet, but we will compute the total demerits and record them in the *minimal_demerits* array, if such a break is the current champion among all ways to get to cur_p in a given line-number class and fitness class.

```

⟨Record a new feasible break 1029⟩ ≡
  if artificial_demerits then d ← 0
  else ⟨Compute the demerits, d, from r to cur_p 1033⟩;
  stat if tracing_paragraphs > 0 then ⟨Print a symbolic description of this feasible break 1030⟩;
  tats
  d ← d + total_demerits(r); { this is the minimum total demerits from the beginning to cur_p via r }
  if d ≤ minimal_demerits[fit_class] then
    begin minimal_demerits[fit_class] ← d; best_place[fit_class] ← break_node(r); best_pl_line[fit_class] ← l;
    if do_last_line_fit then ⟨Store additional data for this feasible break 1847⟩;
    if d < minimum_demerits then minimum_demerits ← d;
  end

```

This code is used in section 1025.

```

1030. ⟨Print a symbolic description of this feasible break 1030⟩ ≡
  begin if printed_node ≠ cur_p then
    ⟨Print the list between printed_node and cur_p, then set printed_node ← cur_p 1031⟩;
  print_nl("@");
  if cur_p = null then print_esc("par")
  else if type(cur_p) ≠ glue_node then
    begin if type(cur_p) = penalty_node then print_esc("penalty")
    else if type(cur_p) = disc_node then print_esc("discretionary")
    else if type(cur_p) = kern_node then print_esc("kern")
    else print_esc("math");
    end;
  print("_via_@@");
  if break_node(r) = null then print_char("0")
  else print_int(serial(break_node(r)));
  print("_b=");
  if b > inf_bad then print_char("*") else print_int(b);
  print("_p="); print_int(pi); print("_d=");
  if artificial_demerits then print_char("*") else print_int(d);
  end

```

This code is used in section 1029.

```

1031. ⟨Print the list between printed_node and cur_p, then set printed_node ← cur_p 1031⟩ ≡
  begin print_nl("");
  if cur_p = null then short_display(link(printed_node))
  else begin save_link ← link(cur_p); link(cur_p) ← null; print_nl("");
    short_display(link(printed_node)); link(cur_p) ← save_link;
  end;
  printed_node ← cur_p;
  end

```

This code is used in section 1030.

1032. When the data for a discretionary break is being displayed, we will have printed the *pre_break* and *post_break* lists; we want to skip over the third list, so that the discretionary data will not appear twice. The following code is performed at the very end of *try_break*.

```

⟨Update the value of printed_node for symbolic displays 1032⟩ ≡
  if cur_p = printed_node then
    if cur_p ≠ null then
      if type(cur_p) = disc_node then
        begin t ← replace_count(cur_p);
        while t > 0 do
          begin decr(t); printed_node ← link(printed_node);
          end;
        end
      end
    end
  end

```

This code is used in section 1003.

```

1033. ⟨Compute the demerits, d, from r to cur_p 1033⟩ ≡
  begin d ← line_penalty + b;
  if abs(d) ≥ 10000 then d ← 100000000 else d ← d * d;
  if pi ≠ 0 then
    if pi > 0 then d ← d + pi * pi
    else if pi > eject_penalty then d ← d - pi * pi;
  if (break_type = hyphenated) ∧ (type(r) = hyphenated) then
    if cur_p ≠ null then d ← d + double_hyphen_demerits
    else d ← d + final_hyphen_demerits;
  if abs(fit_class - fitness(r)) > 1 then d ← d + adj_demerits;
  end

```

This code is used in section 1029.

1034. When an active node disappears, we must delete an adjacent delta node if the active node was at the beginning or the end of the active list, or if it was surrounded by delta nodes. We also must preserve the property that *cur_active_width* represents the length of material from *link*(*prev_r*) to *cur_p*.

```

define combine_two_deltas(#) ≡ mem[prev_r + #].sc ← mem[prev_r + #].sc + mem[r + #].sc
define downdate_width(#) ≡ cur_active_width[#] ← cur_active_width[#] - mem[prev_r + #].sc

⟨Deactivate node r 1034⟩ ≡
  link(prev_r) ← link(r); free_node(r, active_node_size);
  if prev_r = active then ⟨Update the active widths, since the first active node has been deleted 1035⟩
  else if type(prev_r) = delta_node then
    begin r ← link(prev_r);
    if r = last_active then
      begin do_all_eight(downdate_width); link(prev_prev_r) ← last_active;
      free_node(prev_r, delta_node_size); prev_r ← prev_prev_r;
      end
    else if type(r) = delta_node then
      begin do_all_eight(update_width); do_all_eight(combine_two_deltas); link(prev_r) ← link(r);
      free_node(r, delta_node_size);
      end;
    end
  end

```

This code is used in section 1025.

1035. The following code uses the fact that $\text{type}(\text{last_active}) \neq \text{delta_node}$. If the active list has just become empty, we do not need to update the *active_width* array, since it will be initialized when an active node is next inserted.

```

define update_active(#)  $\equiv$  active_width[#]  $\leftarrow$  active_width[#] + mem[r + #].sc
< Update the active widths, since the first active node has been deleted 1035 >  $\equiv$ 
begin r  $\leftarrow$  link(active);
if type(r) = delta_node then
  begin do_all_eight(update_active); do_all_eight(copy_to_cur_active); link(active)  $\leftarrow$  link(r);
  free_node(r, delta_node_size);
  end;
end

```

This code is used in section 1034.

1036. Breaking paragraphs into lines, continued. So far we have gotten a little way into the *line_break* routine, having covered its important *try_break* subroutine. Now let's consider the rest of the process.

The main loop of *line_break* traverses the given hlist, starting at *link(temp_head)*, and calls *try_break* at each legal breakpoint. A variable called *auto_breaking* is set to true except within math formulas, since glue nodes are not legal breakpoints when they appear in formulas.

The current node of interest in the hlist is pointed to by *cur_p*. Another variable, *prev_p*, is usually one step behind *cur_p*, but the real meaning of *prev_p* is this: If *type(cur_p) = glue_node* then *cur_p* is a legal breakpoint if and only if *auto_breaking* is true and *prev_p* does not point to a glue node, penalty node, explicit kern node, or math node.

The following declarations provide for a few other local variables that are used in special calculations.

⟨Local variables for line breaking 1036⟩ ≡
q, r, s, prev_s: *pointer*; { miscellaneous nodes of temporary interest }
f: *internal_font_number*; { used when calculating character widths }

See also section 1068.

This code is used in section 989.

1037. The ‘**loop**’ in the following code is performed at most thrice per call of *line_break*, since it is actually a pass over the entire paragraph.

⟨Find optimal breakpoints 1037⟩ ≡

```

threshold ← pretolerance;
if threshold ≥ 0 then
  begin stat if tracing_paragraphs > 0 then
    begin begin_diagnostic; print_nl("@firstpass"); end; tats
    second_pass ← false; final_pass ← false;
  end
else begin threshold ← tolerance; second_pass ← true; final_pass ← (emergency_stretch ≤ 0);
  stat if tracing_paragraphs > 0 then begin_diagnostic;
  tats
  end;
loop begin if threshold > inf_bad then threshold ← inf_bad;
  if second_pass then ⟨Initialize for hyphenating a paragraph 1066⟩;
  ⟨Create an active breakpoint representing the beginning of the paragraph 1038⟩;
  cur_p ← link(temp_head); auto_breaking ← true;
  prev_p ← cur_p; {glue at beginning is not a legal breakpoint}
  prev_char_p ← null; prev_legal ← null; rejected_cur_p ← null; try_prev_break ← false;
  before_rejected_cur_p ← false; first_p ← cur_p;
  {to access the first node of paragraph as the first active node has break_node = null}
  while (cur_p ≠ null) ∧ (link(active) ≠ last_active) do ⟨Call try_break if cur_p is a legal breakpoint;
    on the second pass, also try to hyphenate the next word, if cur_p is a glue node; then advance
    cur_p to the next node of the paragraph that could possibly be a legal breakpoint 1040⟩;
  if cur_p = null then ⟨Try the final line break at the end of the paragraph, and goto done if the
    desired breakpoints have been found 1047⟩;
  ⟨Clean up the memory by removing the break nodes 1039⟩;
  if ¬second_pass then
    begin stat if tracing_paragraphs > 0 then print_nl("@secondpass"); tats
    threshold ← tolerance; second_pass ← true; final_pass ← (emergency_stretch ≤ 0);
    end {if at first you don't succeed, ...}
  else begin stat if tracing_paragraphs > 0 then print_nl("@emergencypass"); tats
    background[2] ← background[2] + emergency_stretch; final_pass ← true;
    end;
  end;
done: stat if tracing_paragraphs > 0 then
  begin end_diagnostic(true); normalize_selector;
  end;
  tats
  if do_last_line_fit then ⟨Adjust the final line of the paragraph 1850⟩;

```

This code is used in section 989.

1038. The active node that represents the starting point does not need a corresponding passive node.

```

define store_background(#) ≡ active_width[#] ← background[#]
⟨Create an active breakpoint representing the beginning of the paragraph 1038⟩ ≡
q ← get_node(active_node_size); type(q) ← unhyphenated; fitness(q) ← decent_fit; link(q) ← last_active;
break_node(q) ← null; line_number(q) ← prev_graf + 1; total_demerits(q) ← 0; link(active) ← q;
if do_last_line_fit then ⟨Initialize additional fields of the first active node 1842⟩;
do_all_eight(store_background);
passive ← null; printed_node ← temp_head; pass_number ← 0; font_in_short_display ← null_font

```

This code is used in section 1037.

1039. \langle Clean up the memory by removing the break nodes [1039](#) $\rangle \equiv$

```

 $q \leftarrow \text{link}(\text{active});$ 
while  $q \neq \text{last\_active}$  do
  begin  $\text{cur\_p} \leftarrow \text{link}(q);$ 
    if  $\text{type}(q) = \text{delta\_node}$  then  $\text{free\_node}(q, \text{delta\_node\_size})$ 
    else  $\text{free\_node}(q, \text{active\_node\_size});$ 
     $q \leftarrow \text{cur\_p};$ 
  end;
 $q \leftarrow \text{passive};$ 
while  $q \neq \text{null}$  do
  begin  $\text{cur\_p} \leftarrow \text{link}(q); \text{free\_node}(q, \text{passive\_node\_size}); q \leftarrow \text{cur\_p};$ 
  end

```

This code is used in sections [989](#) and [1037](#).

1040. Here is the main switch in the *line_break* routine, where legal breaks are determined. As we move through the hlist, we need to keep the *active_width* array up to date, so that the badness of individual lines is readily calculated by *try_break*. It is convenient to use the short name *act_width* for the component of active width that represents real width as opposed to glue.

```

define act_width  $\equiv$  active_width[1] {length from first active node to current node}
define kern_break  $\equiv$ 
  begin if  $\neg$ is_char_node(link(cur_p))  $\wedge$  auto_breaking then
    if type(link(cur_p)) = glue_node then try_break(0, unhyphenated);
    act_width  $\leftarrow$  act_width + width(cur_p);
  end
  (Call try_break if cur_p is a legal breakpoint; on the second pass, also try to hyphenate the next word, if
   cur_p is a glue node; then advance cur_p to the next node of the paragraph that could possibly be a
   legal breakpoint 1040)  $\equiv$ 
begin if is_char_node(cur_p) then
  (Advance cur_p to the node following the present string of characters 1041);
case type(cur_p) of
  hlist_node, vlist_node, rule_node: act_width  $\leftarrow$  act_width + width(cur_p);
  whatsit_node: (Advance past a whatsit node in the line_break loop 1606);
  glue_node: begin (If node cur_p is a legal breakpoint, call try_break; then update the active widths by
    including the glue in glue_ptr(cur_p) 1042);
    if second_pass  $\wedge$  auto_breaking then (Try to hyphenate the following word 1069);
  end;
  kern_node: if subtype(cur_p) = explicit then kern_break
  else begin act_width  $\leftarrow$  act_width + width(cur_p);
    if (pdf_adjust_spacing > 1)  $\wedge$  (subtype(cur_p) = normal) then
      begin add_kern_stretch(active_width[7])(cur_p); add_kern_shrink(active_width[8])(cur_p);
      end;
    end;
  ligature_node: begin f  $\leftarrow$  font(lig_char(cur_p));
    act_width  $\leftarrow$  act_width + char_width(f)(char_info(f)(character(lig_char(cur_p))));
    if (pdf_adjust_spacing > 1)  $\wedge$  check_expand_pars(f) then
      begin prev_char_p  $\leftarrow$  cur_p; add_char_stretch(active_width[7])(character(lig_char(cur_p)));
      add_char_shrink(active_width[8])(character(lig_char(cur_p)));
      end;
    end;
  disc_node: (Try to break after a discretionary fragment, then goto done5 1043);
  math_node: begin if subtype(cur_p) < L_code then auto_breaking  $\leftarrow$  odd(subtype(cur_p));
    kern_break;
  end;
  penalty_node: try_break(penalty(cur_p), unhyphenated);
  mark_node, ins_node, adjust_node: do_nothing;
othercases confusion("paragraph")
endcases;
  prev_p  $\leftarrow$  cur_p; cur_p  $\leftarrow$  link(cur_p);
done5: end

```

This code is used in section 1037.

1041. The code that passes over the characters of words in a paragraph is part of \TeX 's inner loop, so it has been streamlined for speed. We use the fact that ‘ $\backslash\text{parfillskip}$ ’ glue appears at the end of each paragraph; it is therefore unnecessary to check if $\text{link}(\text{cur_p}) = \text{null}$ when cur_p is a character node.

⟨Advance cur_p to the node following the present string of characters 1041⟩ \equiv

```

begin  $\text{prev\_p} \leftarrow \text{cur\_p}$ ;
repeat  $f \leftarrow \text{font}(\text{cur\_p})$ ;  $\text{act\_width} \leftarrow \text{act\_width} + \text{char\_width}(f)(\text{char\_info}(f)(\text{character}(\text{cur\_p})))$ ;
  if  $(\text{pdf\_adjust\_spacing} > 1) \wedge \text{check\_expand\_pars}(f)$  then
    begin  $\text{prev\_char\_p} \leftarrow \text{cur\_p}$ ;  $\text{add\_char\_stretch}(\text{active\_width}[7])(\text{character}(\text{cur\_p}))$ ;
       $\text{add\_char\_shrink}(\text{active\_width}[8])(\text{character}(\text{cur\_p}))$ ;
    end;
     $\text{cur\_p} \leftarrow \text{link}(\text{cur\_p})$ ;
  until  $\neg \text{is\_char\_node}(\text{cur\_p})$ ;
end

```

This code is used in section 1040.

1042. When node cur_p is a glue node, we look at prev_p to see whether or not a breakpoint is legal at cur_p , as explained above.

⟨If node cur_p is a legal breakpoint, call try_break ; then update the active widths by including the glue in $\text{glue_ptr}(\text{cur_p})$ 1042⟩ \equiv

```

if  $\text{auto\_breaking}$  then
  begin if  $\text{is\_char\_node}(\text{prev\_p})$  then  $\text{try\_break}(0, \text{unhyphenated})$ 
  else if  $\text{precedes\_break}(\text{prev\_p})$  then  $\text{try\_break}(0, \text{unhyphenated})$ 
    else if  $(\text{type}(\text{prev\_p}) = \text{kern\_node}) \wedge (\text{subtype}(\text{prev\_p}) \neq \text{explicit})$  then  $\text{try\_break}(0, \text{unhyphenated})$ ;
  end;
   $\text{check\_shrinkage}(\text{glue\_ptr}(\text{cur\_p}))$ ;  $q \leftarrow \text{glue\_ptr}(\text{cur\_p})$ ;  $\text{act\_width} \leftarrow \text{act\_width} + \text{width}(q)$ ;
   $\text{active\_width}[2 + \text{stretch\_order}(q)] \leftarrow \text{active\_width}[2 + \text{stretch\_order}(q)] + \text{stretch}(q)$ ;
   $\text{active\_width}[6] \leftarrow \text{active\_width}[6] + \text{shrink}(q)$ 

```

This code is used in section 1040.

1043. The following code knows that discretionary texts contain only character nodes, kern nodes, box nodes, rule nodes, and ligature nodes.

⟨Try to break after a discretionary fragment, then **goto** done5 1043⟩ \equiv

```

begin  $s \leftarrow \text{pre\_break}(\text{cur\_p})$ ;  $\text{do\_one\_seven\_eight}(\text{reset\_disc\_width})$ ;
if  $s = \text{null}$  then  $\text{try\_break}(\text{ex\_hyphen\_penalty}, \text{hyphenated})$ 
else begin repeat ⟨Add the width of node  $s$  to  $\text{disc\_width}$  1044⟩;
   $s \leftarrow \text{link}(s)$ ;
until  $s = \text{null}$ ;
   $\text{do\_one\_seven\_eight}(\text{add\_disc\_width\_to\_active\_width})$ ;  $\text{try\_break}(\text{hyphen\_penalty}, \text{hyphenated})$ ;
   $\text{do\_one\_seven\_eight}(\text{sub\_disc\_width\_from\_active\_width})$ ;
end;
 $r \leftarrow \text{replace\_count}(\text{cur\_p})$ ;  $s \leftarrow \text{link}(\text{cur\_p})$ ;
while  $r > 0$  do
  begin ⟨Add the width of node  $s$  to  $\text{act\_width}$  1045⟩;
     $\text{decr}(r)$ ;  $s \leftarrow \text{link}(s)$ ;
  end;
   $\text{prev\_p} \leftarrow \text{cur\_p}$ ;  $\text{cur\_p} \leftarrow s$ ; goto  $\text{done5}$ ;
end

```

This code is used in section 1040.

1044. \langle Add the width of node s to $disc_width$ 1044 $\rangle \equiv$

```

if  $is\_char\_node(s)$  then
  begin  $f \leftarrow font(s)$ ;  $disc\_width[1] \leftarrow disc\_width[1] + char\_width(f)(char\_info(f)(character(s)))$ ;
  if  $(pdf\_adjust\_spacing > 1) \wedge check\_expand\_pars(f)$  then
    begin  $prev\_char\_p \leftarrow s$ ;  $add\_char\_stretch(disc\_width[7])(character(s))$ ;
     $add\_char\_shrink(disc\_width[8])(character(s))$ ;
    end;
  end
else case  $type(s)$  of
   $ligature\_node$ : begin  $f \leftarrow font(lig\_char(s))$ ;
     $disc\_width[1] \leftarrow disc\_width[1] + char\_width(f)(char\_info(f)(character(lig\_char(s))))$ ;
    if  $(pdf\_adjust\_spacing > 1) \wedge check\_expand\_pars(f)$  then
      begin  $prev\_char\_p \leftarrow s$ ;  $add\_char\_stretch(disc\_width[7])(character(lig\_char(s)))$ ;
       $add\_char\_shrink(disc\_width[8])(character(lig\_char(s)))$ ;
      end;
    end;
   $hlist\_node, vlist\_node, rule\_node, kern\_node$ : begin  $disc\_width[1] \leftarrow disc\_width[1] + width(s)$ ;
    if  $(type(s) = kern\_node) \wedge (pdf\_adjust\_spacing > 1) \wedge (subtype(s) = normal)$  then
      begin  $add\_kern\_stretch(disc\_width[7])(s)$ ;  $add\_kern\_shrink(disc\_width[8])(s)$ ;
      end;
    end;
  othercases  $confusion("disc3")$ 
endcases

```

This code is used in section 1043.

1045. \langle Add the width of node s to act_width 1045 $\rangle \equiv$

```

if  $is\_char\_node(s)$  then
  begin  $f \leftarrow font(s)$ ;  $act\_width \leftarrow act\_width + char\_width(f)(char\_info(f)(character(s)))$ ;
  if  $(pdf\_adjust\_spacing > 1) \wedge check\_expand\_pars(f)$  then
    begin  $prev\_char\_p \leftarrow s$ ;  $add\_char\_stretch(active\_width[7])(character(s))$ ;
     $add\_char\_shrink(active\_width[8])(character(s))$ ;
    end;
  end
else case  $type(s)$  of
   $ligature\_node$ : begin  $f \leftarrow font(lig\_char(s))$ ;
     $act\_width \leftarrow act\_width + char\_width(f)(char\_info(f)(character(lig\_char(s))))$ ;
    if  $(pdf\_adjust\_spacing > 1) \wedge check\_expand\_pars(f)$  then
      begin  $prev\_char\_p \leftarrow s$ ;  $add\_char\_stretch(active\_width[7])(character(lig\_char(s)))$ ;
       $add\_char\_shrink(active\_width[8])(character(lig\_char(s)))$ ;
      end;
    end;
   $hlist\_node, vlist\_node, rule\_node, kern\_node$ : begin  $act\_width \leftarrow act\_width + width(s)$ ;
    if  $(type(s) = kern\_node) \wedge (pdf\_adjust\_spacing > 1) \wedge (subtype(s) = normal)$  then
      begin  $add\_kern\_stretch(active\_width[7])(s)$ ;  $add\_kern\_shrink(active\_width[8])(s)$ ;
      end;
    end;
  othercases  $confusion("disc4")$ 
endcases

```

This code is used in section 1043.

1046. The forced line break at the paragraph's end will reduce the list of breakpoints so that all active nodes represent breaks at $cur_p = null$. On the first pass, we insist on finding an active node that has the correct "looseness." On the final pass, there will be at least one active node, and we will match the desired looseness as well as we can.

The global variable $best_bet$ will be set to the active node for the best way to break the paragraph, and a few other variables are used to help determine what is best.

⟨Global variables 13⟩ +≡
 $best_bet$: *pointer*; { use this passive node and its predecessors }
 $fewest_demerits$: *integer*; { the demerits associated with $best_bet$ }
 $best_line$: *halfword*; { line number following the last line of the new paragraph }
 $actual_looseness$: *integer*; { the difference between $line_number(best_bet)$ and the optimum $best_line$ }
 $line_diff$: *integer*; { the difference between the current line number and the optimum $best_line$ }

1047. ⟨Try the final line break at the end of the paragraph, and **goto** *done* if the desired breakpoints have been found 1047⟩ ≡

```
begin try_break(eject_penalty, hyphenated);
if link(active) ≠ last_active then
  begin ⟨Find an active node with fewest demerits 1048⟩;
  if looseness = 0 then goto done;
  ⟨Find the best active node for the desired looseness 1049⟩;
  if (actual_looseness = looseness) ∨ final_pass then goto done;
end;
end
```

This code is used in section 1037.

1048. ⟨Find an active node with fewest demerits 1048⟩ ≡

```
 $r \leftarrow link(active)$ ;  $fewest\_demerits \leftarrow awful\_bad$ ;
repeat if type( $r$ ) ≠ delta_node then
  if total_demerits( $r$ ) < fewest_demerits then
    begin  $fewest\_demerits \leftarrow total\_demerits(r)$ ;  $best\_bet \leftarrow r$ ;
    end;
   $r \leftarrow link(r)$ ;
until  $r = last\_active$ ;
 $best\_line \leftarrow line\_number(best\_bet)$ 
```

This code is used in section 1047.

1049. The adjustment for a desired looseness is a slightly more complicated version of the loop just considered. Note that if a paragraph is broken into segments by displayed equations, each segment will be subject to the looseness calculation, independently of the other segments.

⟨Find the best active node for the desired looseness 1049⟩ ≡

```

begin  $r \leftarrow \text{link}(\text{active})$ ;  $\text{actual\_looseness} \leftarrow 0$ ;
repeat if  $\text{type}(r) \neq \text{delta\_node}$  then
  begin  $\text{line\_diff} \leftarrow \text{line\_number}(r) - \text{best\_line}$ ;
  if  $((\text{line\_diff} < \text{actual\_looseness}) \wedge (\text{looseness} \leq \text{line\_diff})) \vee$ 
     $((\text{line\_diff} > \text{actual\_looseness}) \wedge (\text{looseness} \geq \text{line\_diff}))$  then
    begin  $\text{best\_bet} \leftarrow r$ ;  $\text{actual\_looseness} \leftarrow \text{line\_diff}$ ;  $\text{fewest\_demerits} \leftarrow \text{total\_demerits}(r)$ ;
    end
  else if  $(\text{line\_diff} = \text{actual\_looseness}) \wedge (\text{total\_demerits}(r) < \text{fewest\_demerits})$  then
    begin  $\text{best\_bet} \leftarrow r$ ;  $\text{fewest\_demerits} \leftarrow \text{total\_demerits}(r)$ ;
    end;
  end;
   $r \leftarrow \text{link}(r)$ ;
until  $r = \text{last\_active}$ ;
 $\text{best\_line} \leftarrow \text{line\_number}(\text{best\_bet})$ ;
end

```

This code is used in section 1047.

1050. Once the best sequence of breakpoints has been found (hurray), we call on the procedure *post_line_break* to finish the remainder of the work. (By introducing this subprocedure, we are able to keep *line_break* from getting extremely long.)

⟨Break the paragraph at the chosen breakpoints, justify the resulting lines to the correct widths, and append them to the current vertical list 1050⟩ ≡

```

 $\text{post\_line\_break}(d)$ 

```

This code is used in section 989.

1051. The total number of lines that will be set by *post_line_break* is *best_line* – *prev_graf* – 1. The last breakpoint is specified by *break_node(best_bet)*, and this passive node points to the other breakpoints via the *prev_break* links. The finishing-up phase starts by linking the relevant passive nodes in forward order, changing *prev_break* to *next_break*. (The *next_break* fields actually reside in the same memory space as the *prev_break* fields did, but we give them a new name because of their new significance.) Then the lines are justified, one by one.

```

define next_break  $\equiv$  prev_break { new name for prev_break after links are reversed }
⟨ Declare subprocedures for line_break 1000 ⟩ +=
procedure post_line_break(d : boolean);
  label done, done1;
  var q, r, s: pointer; { temporary registers for list manipulation }
      p, k: pointer; w: scaled; glue_break: boolean; { was a break at glue? }
      ptmp: pointer; disc_break: boolean; { was the current break at a discretionary node? }
      post_disc_break: boolean; { and did it have a nonempty post-break part? }
      cur_width: scaled; { width of line number cur_line }
      cur_indent: scaled; { left margin of line number cur_line }
      t: quarterword; { used for replacement counts in discretionary nodes }
      pen: integer; { use when calculating penalties between lines }
      cur_line: halfword; { the current line number being justified }
      LR_ptr: pointer; { stack of LR codes }
  begin LR_ptr  $\leftarrow$  LR_save;
  ⟨ Reverse the links of the relevant passive nodes, setting cur_p to the first breakpoint 1052 ⟩;
  cur_line  $\leftarrow$  prev_graf + 1;
  repeat ⟨ Justify the line ending at breakpoint cur_p, and append it to the current vertical list, together
    with associated penalties and other insertions 1054 ⟩;
    incr(cur_line); cur_p  $\leftarrow$  next_break(cur_p);
  if cur_p  $\neq$  null then
    if  $\neg$ post_disc_break then ⟨ Prune unwanted nodes at the beginning of the next line 1053 ⟩;
  until cur_p = null;
  if (cur_line  $\neq$  best_line)  $\vee$  (link(temp_head)  $\neq$  null) then confusion("line_breaking");
  prev_graf  $\leftarrow$  best_line – 1; LR_save  $\leftarrow$  LR_ptr;
end;

```

1052. The job of reversing links in a list is conveniently regarded as the job of taking items off one stack and putting them on another. In this case we take them off a stack pointed to by *q* and having *prev_break* fields; we put them on a stack pointed to by *cur_p* and having *next_break* fields. Node *r* is the passive node being moved from stack to stack.

```

⟨ Reverse the links of the relevant passive nodes, setting cur_p to the first breakpoint 1052 ⟩  $\equiv$ 
  q  $\leftarrow$  break_node(best_bet); cur_p  $\leftarrow$  null;
  repeat r  $\leftarrow$  q; q  $\leftarrow$  prev_break(q); next_break(r)  $\leftarrow$  cur_p; cur_p  $\leftarrow$  r;
  until q = null

```

This code is used in section 1051.

1053. Glue and penalty and kern and math nodes are deleted at the beginning of a line, except in the anomalous case that the node to be deleted is actually one of the chosen breakpoints. Otherwise the pruning done here is designed to match the lookahead computation in *try_break*, where the *break_width* values are computed for non-discretionary breakpoints.

```

⟨Prune unwanted nodes at the beginning of the next line 1053⟩ ≡
  begin r ← temp_head;
  loop begin q ← link(r);
    if q = cur_break(cur_p) then goto done1; { cur_break(cur_p) is the next breakpoint }
    { now q cannot be null }
    if is_char_node(q) then goto done1;
    if non_discardable(q) then goto done1;
    if type(q) = kern_node then
      if subtype(q) ≠ explicit then goto done1;
    r ← q; { now type(q) = glue_node, kern_node, math_node, or penalty_node }
    if type(q) = math_node then
      if TeXXeT_en then ⟨Adjust the LR stack for the post_line_break routine 1705⟩;
    end;
done1: if r ≠ temp_head then
  begin link(r) ← null; flush_node_list(link(temp_head)); link(temp_head) ← q;
  end;
end

```

This code is used in section 1051.

1054. The current line to be justified appears in a horizontal list starting at *link*(*temp_head*) and ending at *cur_break*(*cur_p*). If *cur_break*(*cur_p*) is a glue node, we reset the glue to equal the *right_skip* glue; otherwise we append the *right_skip* glue at the right. If *cur_break*(*cur_p*) is a discretionary node, we modify the list so that the discretionary break is compulsory, and we set *disc_break* to *true*. We also append the *left_skip* glue at the left of the line, unless it is zero.

```

⟨Justify the line ending at breakpoint cur_p, and append it to the current vertical list, together with
associated penalties and other insertions 1054⟩ ≡
  if TeXXeT_en then ⟨Insert LR nodes at the beginning of the current line and adjust the LR stack
    based on LR nodes in this line 1704⟩;
  ⟨Modify the end of the line to reflect the nature of the break and to include \rightskip; also set the
    proper value of disc_break 1055⟩;
  if TeXXeT_en then ⟨Insert LR nodes at the end of the current line 1706⟩;
  ⟨Put the \leftskip glue at the left and detach this line 1061⟩;
  ⟨Call the packaging subroutine, setting just_box to the justified box 1064⟩;
  ⟨Append the new box to the current vertical list, followed by the list of special nodes taken out of the
    box by the packager 1063⟩;
  ⟨Append a penalty node, if a nonzero penalty is appropriate 1065⟩

```

This code is used in section 1051.

1055. At the end of the following code, q will point to the final node on the list about to be justified.
 (Modify the end of the line to reflect the nature of the break and to include `\rightskip`; also set the proper value of `disc_break` 1055) \equiv

```

 $q \leftarrow cur\_break(cur\_p)$ ;  $disc\_break \leftarrow false$ ;  $post\_disc\_break \leftarrow false$ ;  $glue\_break \leftarrow false$ ;
if  $q \neq null$  then {  $q$  cannot be a char_node }
  if  $type(q) = glue\_node$  then
    begin  $delete\_glue\_ref(glue\_ptr(q))$ ;  $glue\_ptr(q) \leftarrow right\_skip$ ;  $subtype(q) \leftarrow right\_skip\_code + 1$ ;
     $add\_glue\_ref(right\_skip)$ ;  $glue\_break \leftarrow true$ ; goto done;
  end
else begin if  $type(q) = disc\_node$  then
  (Change discretionary to compulsory and set  $disc\_break \leftarrow true$  1056)
else if  $type(q) = kern\_node$  then  $width(q) \leftarrow 0$ 
  else if  $type(q) = math\_node$  then
    begin  $width(q) \leftarrow 0$ ;
    if TeXXeT-en then (Adjust the LR stack for the post_line_break routine 1705);
    end;
  end
else begin  $q \leftarrow temp\_head$ ;
  while  $link(q) \neq null$  do  $q \leftarrow link(q)$ ;
end;
done: { at this point  $q$  is the rightmost breakpoint; the only exception is the case of a discretionary break
  with non-empty pre_break, then  $q$  has been changed to the last node of the pre_break list }
if  $pdf\_protrude\_chars > 0$  then
  begin
  if  $disc\_break \wedge (is\_char\_node(q) \vee (type(q) \neq disc\_node))$ 
    {  $q$  has been reset to the last node of pre_break }
  then
    begin  $p \leftarrow q$ ;  $ptmp \leftarrow p$ ;
    end
  else begin  $p \leftarrow prev\_rightmost(link(temp\_head), q)$ ; { get  $link(p) = q$  }
     $ptmp \leftarrow p$ ;  $p \leftarrow find\_protchar\_right(link(temp\_head), p)$ ;
    end;  $\textcircled{0}short\_display\_n(p, 1)$ ;  $\textcircled{0}print\_ln$ ;  $\textcircled{0}w \leftarrow right\_pw(p)$ ;
    if  $w \neq 0$  then { we have found a marginal kern, append it after  $ptmp$  }
      begin  $k \leftarrow new\_margin\_kern(-w, last\_rightmost\_char, right\_side)$ ;  $link(k) \leftarrow link(ptmp)$ ;
       $link(ptmp) \leftarrow k$ ;
      if  $(ptmp = q)$  then  $q \leftarrow link(q)$ ;
      end;
    end ; { if  $q$  was not a breakpoint at glue and has been reset to rightskip then we append rightskip
    after  $q$  now }
    if  $\neg glue\_break$  then
      begin (Put the \rightskip glue after node  $q$  1060);
      end;
  
```

This code is used in section 1054.

1056. (Change discretionary to compulsory and set $disc_break \leftarrow true$ 1056) \equiv

```

begin  $t \leftarrow replace\_count(q)$ ;
  (Destroy the  $t$  nodes following  $q$ , and make  $r$  point to the following node 1057);
  if  $post\_break(q) \neq null$  then (Transplant the post-break list 1058);
  if  $pre\_break(q) \neq null$  then (Transplant the pre-break list 1059);
   $link(q) \leftarrow r$ ;  $disc\_break \leftarrow true$ ;
end

```

This code is used in section 1055.

1057. \langle Destroy the t nodes following q , and make r point to the following node [1057](#) $\rangle \equiv$
if $t = 0$ **then** $r \leftarrow \text{link}(q)$
else begin $r \leftarrow q$;
 while $t > 1$ **do**
 begin $r \leftarrow \text{link}(r)$; $\text{decr}(t)$;
 end;
 $s \leftarrow \text{link}(r)$; $r \leftarrow \text{link}(s)$; $\text{link}(s) \leftarrow \text{null}$; $\text{flush_node_list}(\text{link}(q))$; $\text{replace_count}(q) \leftarrow 0$;
end

This code is used in section [1056](#).

1058. We move the post-break list from inside node q to the main list by reattaching it just before the present node r , then resetting r .

\langle Transplant the post-break list [1058](#) $\rangle \equiv$
begin $s \leftarrow \text{post_break}(q)$;
while $\text{link}(s) \neq \text{null}$ **do** $s \leftarrow \text{link}(s)$;
 $\text{link}(s) \leftarrow r$; $r \leftarrow \text{post_break}(q)$; $\text{post_break}(q) \leftarrow \text{null}$; $\text{post_disc_break} \leftarrow \text{true}$;
end

This code is used in section [1056](#).

1059. We move the pre-break list from inside node q to the main list by reattaching it just after the present node q , then resetting q .

\langle Transplant the pre-break list [1059](#) $\rangle \equiv$
begin $s \leftarrow \text{pre_break}(q)$; $\text{link}(q) \leftarrow s$;
while $\text{link}(s) \neq \text{null}$ **do** $s \leftarrow \text{link}(s)$;
 $\text{pre_break}(q) \leftarrow \text{null}$; $q \leftarrow s$;
end

This code is used in section [1056](#).

1060. \langle Put the `\rightskip` glue after node q [1060](#) $\rangle \equiv$
 $r \leftarrow \text{new_param_glue}(\text{right_skip_code})$; $\text{link}(r) \leftarrow \text{link}(q)$; $\text{link}(q) \leftarrow r$; $q \leftarrow r$

This code is used in section [1055](#).

1061. The following code begins with q at the end of the list to be justified. It ends with q at the beginning of that list, and with $\text{link}(\text{temp_head})$ pointing to the remainder of the paragraph, if any.

\langle Put the `\leftskip` glue at the left and detach this line [1061](#) $\rangle \equiv$
 $r \leftarrow \text{link}(q)$; $\text{link}(q) \leftarrow \text{null}$; $q \leftarrow \text{link}(\text{temp_head})$; $\text{link}(\text{temp_head}) \leftarrow r$;
 { at this point q is the leftmost node; all discardable nodes have been discarded }
if $\text{pdf_protrude_chars} > 0$ **then**
 begin $p \leftarrow q$; $p \leftarrow \text{find_protchar_left}(p, \text{false})$; { no more discardables }
 $w \leftarrow \text{left_pw}(p)$;
 if $w \neq 0$ **then**
 begin $k \leftarrow \text{new_margin_kern}(-w, \text{last_leftmost_char}, \text{left_side})$; $\text{link}(k) \leftarrow q$; $q \leftarrow k$;
 end;
 end;
if $\text{left_skip} \neq \text{zero_glue}$ **then**
 begin $r \leftarrow \text{new_param_glue}(\text{left_skip_code})$; $\text{link}(r) \leftarrow q$; $q \leftarrow r$;
 end

This code is used in section [1054](#).

1062. \langle Initialize table entries (done by INITEX only) 182 $\rangle \equiv$
 $pdf_ignored_dimen \leftarrow ignore_depth$; $pdf_each_line_height \leftarrow pdf_ignored_dimen$;
 $pdf_each_line_depth \leftarrow pdf_ignored_dimen$; $pdf_first_line_height \leftarrow pdf_ignored_dimen$;
 $pdf_last_line_depth \leftarrow pdf_ignored_dimen$;

1063. \langle Append the new box to the current vertical list, followed by the list of special nodes taken out of the box by the packager 1063 $\rangle \equiv$
if $pdf_each_line_height \neq pdf_ignored_dimen$ **then** $height(just_box) \leftarrow pdf_each_line_height$;
if $pdf_each_line_depth \neq pdf_ignored_dimen$ **then** $depth(just_box) \leftarrow pdf_each_line_depth$;
if $(pdf_first_line_height \neq pdf_ignored_dimen) \wedge (cur_line = prev_graf + 1)$ **then**
 $height(just_box) \leftarrow pdf_first_line_height$;
if $(pdf_last_line_depth \neq pdf_ignored_dimen) \wedge (cur_line + 1 = best_line)$ **then**
 $depth(just_box) \leftarrow pdf_last_line_depth$;
if $pre_adjust_head \neq pre_adjust_tail$ **then** $append_list(pre_adjust_head)(pre_adjust_tail)$;
 $pre_adjust_tail \leftarrow null$; $append_to_vlist(just_box)$;
if $adjust_head \neq adjust_tail$ **then** $append_list(adjust_head)(adjust_tail)$;
 $adjust_tail \leftarrow null$

This code is used in section 1054.

1064. Now q points to the hlist that represents the current line of the paragraph. We need to compute the appropriate line width, pack the line into a box of this size, and shift the box by the appropriate amount of indentation.

\langle Call the packaging subroutine, setting $just_box$ to the justified box 1064 $\rangle \equiv$
if $cur_line > last_special_line$ **then**
 $begin$ $cur_width \leftarrow second_width$; $cur_indent \leftarrow second_indent$;
end
else if $par_shape_ptr = null$ **then**
 $begin$ $cur_width \leftarrow first_width$; $cur_indent \leftarrow first_indent$;
end
else begin $cur_width \leftarrow mem[par_shape_ptr + 2 * cur_line].sc$;
 $cur_indent \leftarrow mem[par_shape_ptr + 2 * cur_line - 1].sc$;
end;
 $adjust_tail \leftarrow adjust_head$; $pre_adjust_tail \leftarrow pre_adjust_head$;
if $pdf_adjust_spacing > 0$ **then** $just_box \leftarrow hpack(q, cur_width, cal_expand_ratio)$
else $just_box \leftarrow hpack(q, cur_width, exactly)$;
 $shift_amount(just_box) \leftarrow cur_indent$

This code is used in section 1054.

1065. Penalties between the lines of a paragraph come from club and widow lines, from the *inter_line_penalty* parameter, and from lines that end at discretionary breaks. Breaking between lines of a two-line paragraph gets both club-line and widow-line penalties. The local variable *pen* will be set to the sum of all relevant penalties for the current line, except that the final line is never penalized.

⟨Append a penalty node, if a nonzero penalty is appropriate 1065⟩ ≡

```

if cur_line + 1 ≠ best_line then
  begin q ← inter_line_penalties_ptr;
  if q ≠ null then
    begin r ← cur_line;
    if r > penalty(q) then r ← penalty(q);
    pen ← penalty(q + r);
    end
  else pen ← inter_line_penalty;
  q ← club_penalties_ptr;
  if q ≠ null then
    begin r ← cur_line − prev_graf;
    if r > penalty(q) then r ← penalty(q);
    pen ← pen + penalty(q + r);
    end
  else if cur_line = prev_graf + 1 then pen ← pen + club_penalty;
  if d then q ← display_widow_penalties_ptr
  else q ← widow_penalties_ptr;
  if q ≠ null then
    begin r ← best_line − cur_line − 1;
    if r > penalty(q) then r ← penalty(q);
    pen ← pen + penalty(q + r);
    end
  else if cur_line + 2 = best_line then
    if d then pen ← pen + display_widow_penalty
    else pen ← pen + widow_penalty;
  if disc_break then pen ← pen + broken_penalty;
  if pen ≠ 0 then
    begin r ← new_penalty(pen); link(tail) ← r; tail ← r;
    end;
  end

```

This code is used in section 1054.

1066. Pre-hyphenation. When the line-breaking routine is unable to find a feasible sequence of break-points, it makes a second pass over the paragraph, attempting to hyphenate the hyphenatable words. The goal of hyphenation is to insert discretionary material into the paragraph so that there are more potential places to break.

The general rules for hyphenation are somewhat complex and technical, because we want to be able to hyphenate words that are preceded or followed by punctuation marks, and because we want the rules to work for languages other than English. We also must contend with the fact that hyphens might radically alter the ligature and kerning structure of a word.

A sequence of characters will be considered for hyphenation only if it belongs to a “potentially hyphenatable part” of the current paragraph. This is a sequence of nodes $p_0 p_1 \dots p_m$ where p_0 is a glue node, $p_1 \dots p_{m-1}$ are either character or ligature or whatsit or implicit kern or text direction nodes, and p_m is a glue or penalty or insertion or adjust or mark or whatsit or explicit kern node. (Therefore hyphenation is disabled by boxes, math formulas, and discretionary nodes already inserted by the user.) The ligature nodes among $p_1 \dots p_{m-1}$ are effectively expanded into the original non-ligature characters; the kern nodes and whatsits are ignored. Each character c is now classified as either a nonletter (if $lc_code(c) = 0$), a lowercase letter (if $lc_code(c) = c$), or an uppercase letter (otherwise); an uppercase letter is treated as if it were $lc_code(c)$ for purposes of hyphenation. The characters generated by $p_1 \dots p_{m-1}$ may begin with nonletters; let c_1 be the first letter that is not in the middle of a ligature. Whatsit nodes preceding c_1 are ignored; a whatsit found after c_1 will be the terminating node p_m . All characters that do not have the same font as c_1 will be treated as nonletters. The *hyphen_char* for that font must be between 0 and 255, otherwise hyphenation will not be attempted. TeX looks ahead for as many consecutive letters $c_1 \dots c_n$ as possible; however, n must be less than 64, so a character that would otherwise be c_{64} is effectively not a letter. Furthermore c_n must not be in the middle of a ligature. In this way we obtain a string of letters $c_1 \dots c_n$ that are generated by nodes $p_a \dots p_b$, where $1 \leq a \leq b + 1 \leq m$. If $n \geq l_hyf + r_hyf$, this string qualifies for hyphenation; however, uc_hyph must be positive, if c_1 is uppercase.

The hyphenation process takes place in three stages. First, the candidate sequence $c_1 \dots c_n$ is found; then potential positions for hyphens are determined by referring to hyphenation tables; and finally, the nodes $p_a \dots p_b$ are replaced by a new sequence of nodes that includes the discretionary breaks found.

Fortunately, we do not have to do all this calculation very often, because of the way it has been taken out of TeX’s inner loop. For example, when the second edition of the author’s 700-page book *Seminumerical Algorithms* was typeset by TeX, only about 1.2 hyphenations needed to be tried per paragraph, since the line breaking algorithm needed to use two passes on only about 5 per cent of the paragraphs.

\langle Initialize for hyphenating a paragraph 1066 $\rangle \equiv$

```
begin init if trie_not_ready then init_trie;
tini
  cur_lang  $\leftarrow$  init_cur_lang; l_hyf  $\leftarrow$  init_l_hyf; r_hyf  $\leftarrow$  init_r_hyf; set_hyph_index;
end
```

This code is used in section 1037.

1067. The letters $c_1 \dots c_n$ that are candidates for hyphenation are placed into an array called *hc*; the number *n* is placed into *hn*; pointers to nodes p_{a-1} and p_b in the description above are placed into variables *ha* and *hb*; and the font number is placed into *hf*.

```

⟨Global variables 13⟩ +≡
hc: array [0 .. 65] of 0 .. 256; { word to be hyphenated }
hn: 0 .. 64; { the number of positions occupied in hc; not always a small_number }
ha, hb: pointer; { nodes ha .. hb should be replaced by the hyphenated result }
hf: internal_font_number; { font number of the letters in hc }
hu: array [0 .. 63] of 0 .. 256; { like hc, before conversion to lowercase }
hyf_char: integer; { hyphen character of the relevant font }
cur_lang, init_cur_lang: ASCII_code; { current hyphenation table of interest }
l_hyf, r_hyf, init_l_hyf, init_r_hyf: integer; { limits on fragment sizes }
hyf_bchar: halfword; { boundary character after  $c_n$  }

```

1068. Hyphenation routines need a few more local variables.

```

⟨Local variables for line breaking 1036⟩ +≡
j: small_number; { an index into hc or hu }
c: 0 .. 255; { character being considered for hyphenation }

```

1069. When the following code is activated, the *line_break* procedure is in its second pass, and *cur_p* points to a glue node.

```

⟨Try to hyphenate the following word 1069⟩ ≡
begin prev_s ← cur_p; s ← link(prev_s);
if s ≠ null then
  begin ⟨Skip to node ha, or goto done1 if no hyphenation should be attempted 1071⟩;
  if l_hyf + r_hyf > 63 then goto done1;
  ⟨Skip to node hb, putting letters into hu and hc 1072⟩;
  ⟨Check that the nodes following hb permit hyphenation and that at least l_hyf + r_hyf letters have
    been found, otherwise goto done1 1074⟩;
  hyphenate;
  end;
done1: end

```

This code is used in section 1040.

1070. ⟨Declare subprocedures for *line_break* 1000⟩ +≡

⟨Declare the function called *reconstitute* 1081⟩

```

procedure hyphenate;
  label common_ending, done, found, found1, found2, not_found, exit;
  var ⟨Local variables for hyphenation 1076⟩
  begin ⟨Find hyphen locations for the word in hc, or return 1098⟩;
  ⟨If no hyphens were found, return 1077⟩;
  ⟨Replace nodes ha .. hb by a sequence of nodes that includes the discretionary hyphens 1078⟩;
exit: end;

```

1071. The first thing we need to do is find the node *ha* just before the first letter.

⟨Skip to node *ha*, or **goto** *done1* if no hyphenation should be attempted 1071⟩ ≡

```

loop begin if is_char_node(s) then
  begin c ← qo(character(s)); hf ← font(s);
  end
else if type(s) = ligature_node then
  if lig_ptr(s) = null then goto continue
  else begin q ← lig_ptr(s); c ← qo(character(q)); hf ← font(q);
  end
else if (type(s) = kern_node) ∧ (subtype(s) = normal) then goto continue
else if (type(s) = math_node) ∧ (subtype(s) ≥ L_code) then goto continue
else if type(s) = whatsit_node then
  begin ⟨Advance past a whatsit node in the pre-hyphenation loop 1607⟩;
  goto continue;
  end
else goto done1;
set_lc_code(c);
if hc[0] ≠ 0 then
  if (hc[0] = c) ∨ (uc_hyph > 0) then goto done2
  else goto done1;
continue: prev_s ← s; s ← link(prev_s);
end;
done2: hyf_char ← hyphen_char[hf];
if hyf_char < 0 then goto done1;
if hyf_char > 255 then goto done1;
ha ← prev_s

```

This code is used in section 1069.

1072. The word to be hyphenated is now moved to the *hu* and *hc* arrays.

⟨Skip to node *hb*, putting letters into *hu* and *hc* 1072⟩ ≡

```

hn ← 0;
loop begin if is_char_node(s) then
  begin if font(s) ≠ hf then goto done3;
  hyf_bchar ← character(s); c ← qo(hyf_bchar); set_lc_code(c);
  if hc[0] = 0 then goto done3;
  if hn = 63 then goto done3;
  hb ← s; incr(hn); hu[hn] ← c; hc[hn] ← hc[0]; hyf_bchar ← non_char;
  end
else if type(s) = ligature_node then ⟨Move the characters of a ligature node to hu and hc; but goto
  done3 if they are not all letters 1073⟩
else if (type(s) = kern_node) ∧ (subtype(s) = normal) then
  begin hb ← s; hyf_bchar ← font_bchar[hf];
  end
  else goto done3;
s ← link(s);
end;
done3:

```

This code is used in section 1069.

1073. We let j be the index of the character being stored when a ligature node is being expanded, since we do not want to advance hn until we are sure that the entire ligature consists of letters. Note that it is possible to get to *done3* with $hn = 0$ and hb not set to any value.

```

⟨ Move the characters of a ligature node to  $hu$  and  $hc$ ; but goto done3 if they are not all letters 1073 ⟩ ≡
begin if  $font(lig\_char(s)) \neq hf$  then goto done3;
 $j \leftarrow hn$ ;  $q \leftarrow lig\_ptr(s)$ ; if  $q > null$  then  $hyf\_bchar \leftarrow character(q)$ ;
while  $q > null$  do
  begin  $c \leftarrow qo(character(q))$ ;  $set\_lc\_code(c)$ ;
  if  $hc[0] = 0$  then goto done3;
  if  $j = 63$  then goto done3;
   $incr(j)$ ;  $hu[j] \leftarrow c$ ;  $hc[j] \leftarrow hc[0]$ ;
   $q \leftarrow link(q)$ ;
end;
 $hb \leftarrow s$ ;  $hn \leftarrow j$ ;
if  $odd(subtype(s))$  then  $hyf\_bchar \leftarrow font\_bchar[hf]$  else  $hyf\_bchar \leftarrow non\_char$ ;
end

```

This code is used in section 1072.

1074. ⟨ Check that the nodes following hb permit hyphenation and that at least $l_hyf + r_hyf$ letters have been found, otherwise **goto** *done1* 1074 ⟩ ≡

```

if  $hn < l\_hyf + r\_hyf$  then goto done1; {  $l\_hyf$  and  $r\_hyf$  are  $\geq 1$  }
loop begin if  $\neg(is\_char\_node(s))$  then
  case  $type(s)$  of
    ligature_node:  $do\_nothing$ ;
    kern_node: if  $subtype(s) \neq normal$  then goto done4;
    whatsit_node, glue_node, penalty_node, ins_node, adjust_node, mark_node: goto done4;
    math_node: if  $subtype(s) \geq L\_code$  then goto done4 else goto done1;
    othercases goto done1
  endcases;
   $s \leftarrow link(s)$ ;
end;
done4:

```

This code is used in section 1069.

1075. Post-hyphenation. If a hyphen may be inserted between $hc[j]$ and $hc[j + 1]$, the hyphenation procedure will set $hyf[j]$ to some small odd number. But before we look at T_EX's hyphenation procedure, which is independent of the rest of the line-breaking algorithm, let us consider what we will do with the hyphens it finds, since it is better to work on this part of the program before forgetting what ha and hb , etc., are all about.

⟨Global variables 13⟩ +≡

hyf : **array** [0 .. 64] **of** 0 .. 9; { odd values indicate discretionary hyphens }

$init_list$: *pointer*; { list of punctuation characters preceding the word }

$init_lig$: *boolean*; { does $init_list$ represent a ligature? }

$init_lft$: *boolean*; { if so, did the ligature involve a left boundary? }

1076. ⟨Local variables for hyphenation 1076⟩ ≡

i, j, l : 0 .. 65; { indices into hc or hu }

q, r, s : *pointer*; { temporary registers for list manipulation }

$bchar$: *halfword*; { boundary character of hyphenated word, or *non_char* }

See also sections 1087, 1097, and 1104.

This code is used in section 1070.

1077. T_EX will never insert a hyphen that has fewer than $\backslash\mathrm{lefthyphenmin}$ letters before it or fewer than $\backslash\mathrm{righthyphenmin}$ after it; hence, a short word has comparatively little chance of being hyphenated. If no hyphens have been found, we can save time by not having to make any changes to the paragraph.

⟨If no hyphens were found, **return** 1077⟩ ≡

for $j \leftarrow l_hyf$ **to** $hn - r_hyf$ **do**

if $odd(hyf[j])$ **then goto** *found1*;

return;

found1:

This code is used in section 1070.

1078. If hyphens are in fact going to be inserted, TeX first deletes the subsequence of nodes between *ha* and *hb*. An attempt is made to preserve the effect that implicit boundary characters and punctuation marks had on ligatures inside the hyphenated word, by storing a left boundary or preceding character in *hu*[0] and by storing a possible right boundary in *bchar*. We set $j \leftarrow 0$ if *hu*[0] is to be part of the reconstruction; otherwise $j \leftarrow 1$. The variable *s* will point to the tail of the current hlist, and *q* will point to the node following *hb*, so that things can be hooked up after we reconstitute the hyphenated word.

```

⟨ Replace nodes ha .. hb by a sequence of nodes that includes the discretionary hyphens 1078 ⟩ ≡
  q ← link(hb); link(hb) ← null; r ← link(ha); link(ha) ← null; bchar ← hyf_bchar;
  if is_char_node(ha) then
    if font(ha) ≠ hf then goto found2
    else begin init_list ← ha; init_lig ← false; hu[0] ← qo(character(ha));
    end
  else if type(ha) = ligature_node then
    if font(lig_char(ha)) ≠ hf then goto found2
    else begin init_list ← lig_ptr(ha); init_lig ← true; init_lft ← (subtype(ha) > 1);
    hu[0] ← qo(character(lig_char(ha)));
    if init_list = null then
      if init_lft then
        begin hu[0] ← 256; init_lig ← false;
        end; { in this case a ligature will be reconstructed from scratch }
      free_node(ha, small_node_size);
    end
  else begin { no punctuation found; look for left boundary }
    if ¬is_char_node(r) then
      if type(r) = ligature_node then
        if subtype(r) > 1 then goto found2;
         $j \leftarrow 1$ ; s ← ha; init_list ← null; goto common_ending;
      end;
    s ← cur_p; { we have cur_p ≠ ha because type(cur_p) = glue_node }
    while link(s) ≠ ha do s ← link(s);
     $j \leftarrow 0$ ; goto common_ending;
  found2: s ← ha;  $j \leftarrow 0$ ; hu[0] ← 256; init_lig ← false; init_list ← null;
  common_ending: flush_node_list(r);
  ⟨ Reconstitute nodes for the hyphenated word, inserting discretionary hyphens 1088 ⟩;
  flush_list(init_list)

```

This code is used in section 1070.

1079. We must now face the fact that the battle is not over, even though the hyphens have been found: The process of reconstituting a word can be nontrivial because ligatures might change when a hyphen is present. The TeXbook discusses the difficulties of the word “difficult”, and the discretionary material surrounding a hyphen can be considerably more complex than that. Suppose *abcdef* is a word in a font for which the only ligatures are *bc*, *cd*, *de*, and *ef*. If this word permits hyphenation between *b* and *c*, the two patterns with and without hyphenation are *a b - cd ef* and *a bc de f*. Thus the insertion of a hyphen might cause effects to ripple arbitrarily far into the rest of the word. A further complication arises if additional hyphens appear together with such rippling, e.g., if the word in the example just given could also be hyphenated between *c* and *d*; TeX avoids this by simply ignoring the additional hyphens in such weird cases.

Still further complications arise in the presence of ligatures that do not delete the original characters. When punctuation precedes the word being hyphenated, TeX’s method is not perfect under all possible scenarios, because punctuation marks and letters can propagate information back and forth. For example, suppose the original pre-hyphenation pair **a* changes to **y* via a *l=:* ligature, which changes to *xy* via a *=:l* ligature; if $p_{a-1} = x$ and $p_a = y$, the reconstitution procedure isn’t smart enough to obtain *xy* again. In such cases the font designer should include a ligature that goes from *xa* to *xy*.

1080. The processing is facilitated by a subroutine called *reconstitute*. Given a string of characters $x_j \dots x_n$, there is a smallest index $m \geq j$ such that the “translation” of $x_j \dots x_n$ by ligatures and kerning has the form $y_1 \dots y_t$ followed by the translation of $x_{m+1} \dots x_n$, where $y_1 \dots y_t$ is some nonempty sequence of character, ligature, and kern nodes. We call $x_j \dots x_m$ a “cut prefix” of $x_j \dots x_n$. For example, if $x_1 x_2 x_3 = \text{fly}$, and if the font contains ‘fl’ as a ligature and a kern between ‘fl’ and ‘y’, then $m = 2$, $t = 2$, and y_1 will be a ligature node for ‘fl’ followed by an appropriate kern node y_2 . In the most common case, x_j forms no ligature with x_{j+1} and we simply have $m = j$, $y_1 = x_j$. If $m < n$ we can repeat the procedure on $x_{m+1} \dots x_n$ until the entire translation has been found.

The *reconstitute* function returns the integer m and puts the nodes $y_1 \dots y_t$ into a linked list starting at *link(hold_head)*, getting the input $x_j \dots x_n$ from the *hu* array. If $x_j = 256$, we consider x_j to be an implicit left boundary character; in this case j must be strictly less than n . There is a parameter *bchar*, which is either 256 or an implicit right boundary character assumed to be present just following x_n . (The value *hu*[$n + 1$] is never explicitly examined, but the algorithm imagines that *bchar* is there.)

If there exists an index k in the range $j \leq k \leq m$ such that *hyf*[k] is odd and such that the result of *reconstitute* would have been different if x_{k+1} had been *hchar*, then *reconstitute* sets *hyphen_passed* to the smallest such k . Otherwise it sets *hyphen_passed* to zero.

A special convention is used in the case $j = 0$: Then we assume that the translation of *hu*[0] appears in a special list of charnodes starting at *init_list*; moreover, if *init_lig* is *true*, then *hu*[0] will be a ligature character, involving a left boundary if *init_lft* is *true*. This facility is provided for cases when a hyphenated word is preceded by punctuation (like single or double quotes) that might affect the translation of the beginning of the word.

⟨Global variables 13⟩ +≡

hyphen_passed: *small_number*; { first hyphen in a ligature, if any }

1081. ⟨Declare the function called *reconstitute* 1081⟩ ≡

function *reconstitute*(*j*, *n* : *small_number*; *bchar*, *hchar* : *halfword*): *small_number*;

label *continue*, *done*;

var *p*: *pointer*; { temporary register for list manipulation }

t: *pointer*; { a node being appended to }

q: *four_quarters*; { character information or a lig/kern instruction }

cur_rh: *halfword*; { hyphen character for ligature testing }

test_char: *halfword*; { hyphen or other character for ligature testing }

w: *scaled*; { amount of kerning }

k: *font_index*; { position of current lig/kern instruction }

begin *hyphen_passed* ← 0; *t* ← *hold_head*; *w* ← 0; *link(hold_head)* ← *null*;

 { at this point *ligature_present* = *lft_hit* = *rt_hit* = *false* }

 ⟨Set up data structures with the cursor following position *j* 1083⟩;

continue: ⟨If there’s a ligature or kern at the cursor position, update the data structures, possibly advancing *j*; continue until the cursor moves 1084⟩;

 ⟨Append a ligature and/or kern to the translation; **goto** *continue* if the stack of inserted ligatures is nonempty 1085⟩;

reconstitute ← *j*;

end;

This code is used in section 1070.

1082. The reconstitution procedure shares many of the global data structures by which T_EX has processed the words before they were hyphenated. There is an implied “cursor” between characters *cur_l* and *cur_r*; these characters will be tested for possible ligature activity. If *ligature_present* then *cur_l* is a ligature character formed from the original characters following *cur_q* in the current translation list. There is a “ligature stack” between the cursor and character *j + 1*, consisting of pseudo-ligature nodes linked together by their *link* fields. This stack is normally empty unless a ligature command has created a new character that will need to be processed later. A pseudo-ligature is a special node having a *character* field that represents a potential ligature and a *lig_ptr* field that points to a *char_node* or is *null*. We have

$$cur_r = \begin{cases} character(lig_stack), & \text{if } lig_stack > null; \\ qi(hu[j+1]), & \text{if } lig_stack = null \text{ and } j < n; \\ bchar, & \text{if } lig_stack = null \text{ and } j = n. \end{cases}$$

⟨Global variables 13⟩ +≡

cur_l, cur_r: *halfword*; {characters before and after the cursor}
cur_q: *pointer*; {where a ligature should be detached}
lig_stack: *pointer*; {unfinished business to the right of the cursor}
ligature_present: *boolean*; {should a ligature node be made for *cur_l*?}
lft_hit, rt_hit: *boolean*; {did we hit a ligature with a boundary character?}

1083. define *append_charnode_to_t*(#) ≡
 begin *link*(*t*) ← *get_avail*; *t* ← *link*(*t*); *font*(*t*) ← *hf*; *character*(*t*) ← #;
 end
define *set_cur_r* ≡
 begin if *j* < *n* **then** *cur_r* ← *qi*(*hu*[*j* + 1]) **else** *cur_r* ← *bchar*;
 if *odd*(*hyf*[*j*]) **then** *cur_rh* ← *hchar* **else** *cur_rh* ← *non_char*;
 end

⟨Set up data structures with the cursor following position *j* 1083⟩ ≡

cur_l ← *qi*(*hu*[*j*]); *cur_q* ← *t*;
if *j* = 0 **then**
 begin *ligature_present* ← *init_lig*; *p* ← *init_list*;
 if *ligature_present* **then** *lft_hit* ← *init_lft*;
 while *p* > *null* **do**
 begin *append_charnode_to_t*(*character*(*p*)); *p* ← *link*(*p*);
 end;
 end
else if *cur_l* < *non_char* **then** *append_charnode_to_t*(*cur_l*);
 lig_stack ← *null*; *set_cur_r*

This code is used in section 1081.

1084. We may want to look at the lig/kern program twice, once for a hyphen and once for a normal letter. (The hyphen might appear after the letter in the program, so we'd better not try to look for both at once.)

⟨ If there's a ligature or kern at the cursor position, update the data structures, possibly advancing j ;

continue until the cursor moves 1084) \equiv

```

if  $cur\_l = non\_char$  then
  begin  $k \leftarrow bchar\_label[hf]$ ;
  if  $k = non\_address$  then goto done else  $q \leftarrow font\_info[k].qqqq$ ;
  end
else begin  $q \leftarrow char\_info(hf)(cur\_l)$ ;
  if  $char\_tag(q) \neq lig\_tag$  then goto done;
   $k \leftarrow lig\_kern\_start(hf)(q)$ ;  $q \leftarrow font\_info[k].qqqq$ ;
  if  $skip\_byte(q) > stop\_flag$  then
    begin  $k \leftarrow lig\_kern\_restart(hf)(q)$ ;  $q \leftarrow font\_info[k].qqqq$ ;
    end;
  end; { now  $k$  is the starting address of the lig/kern program }
if  $cur\_rh < non\_char$  then  $test\_char \leftarrow cur\_rh$  else  $test\_char \leftarrow cur\_r$ ;
loop begin if  $next\_char(q) = test\_char$  then
  if  $skip\_byte(q) \leq stop\_flag$  then
    if  $cur\_rh < non\_char$  then
      begin  $hyphen\_passed \leftarrow j$ ;  $hchar \leftarrow non\_char$ ;  $cur\_rh \leftarrow non\_char$ ; goto continue;
      end
    else begin if  $hchar < non\_char$  then
      if  $odd(hyf[j])$  then
        begin  $hyphen\_passed \leftarrow j$ ;  $hchar \leftarrow non\_char$ ;
        end;
      if  $op\_byte(q) < kern\_flag$  then
        ⟨ Carry out a ligature replacement, updating the cursor structure and possibly advancing  $j$ ;
        goto continue if the cursor doesn't advance, otherwise goto done 1086);
         $w \leftarrow char\_kern(hf)(q)$ ; goto done; { this kern will be inserted below }
      end;
    if  $skip\_byte(q) \geq stop\_flag$  then
      if  $cur\_rh = non\_char$  then goto done
      else begin  $cur\_rh \leftarrow non\_char$ ; goto continue;
      end;
     $k \leftarrow k + qo(skip\_byte(q)) + 1$ ;  $q \leftarrow font\_info[k].qqqq$ ;
  end;
done:
```

This code is used in section 1081.

```

1085. define wrap_lig(#)  $\equiv$ 
    if ligature_present then
        begin p  $\leftarrow$  new_ligature(hf, cur_l, link(cur_q));
        if lft_hit then
            begin subtype(p)  $\leftarrow$  2; lft_hit  $\leftarrow$  false;
            end;
        if # then
            if lig_stack = null then
                begin incr(subtype(p)); rt_hit  $\leftarrow$  false;
                end;
            link(cur_q)  $\leftarrow$  p; t  $\leftarrow$  p; ligature_present  $\leftarrow$  false;
            end
        define pop_lig_stack  $\equiv$ 
            begin if lig_ptr(lig_stack) > null then
                begin link(t)  $\leftarrow$  lig_ptr(lig_stack); { this is a charnode for hu[j + 1] }
                t  $\leftarrow$  link(t); incr(j);
                end;
                p  $\leftarrow$  lig_stack; lig_stack  $\leftarrow$  link(p); free_node(p, small_node_size);
                if lig_stack = null then set_cur_r else cur_r  $\leftarrow$  character(lig_stack);
                end { if lig_stack isn't null we have cur_rh = non_char }
    end

```

⟨ Append a ligature and/or kern to the translation; **goto** *continue* if the stack of inserted ligatures is nonempty 1085 ⟩ \equiv

```

wrap_lig(rt_hit);
if w  $\neq$  0 then
    begin link(t)  $\leftarrow$  new_kern(w); t  $\leftarrow$  link(t); w  $\leftarrow$  0;
    end;
if lig_stack > null then
    begin cur_q  $\leftarrow$  t; cur_l  $\leftarrow$  character(lig_stack); ligature_present  $\leftarrow$  true; pop_lig_stack;
    goto continue;
end

```

This code is used in section 1081.

1086. \langle Carry out a ligature replacement, updating the cursor structure and possibly advancing j ; **goto** *continue* if the cursor doesn't advance, otherwise **goto** *done* 1086 $\rangle \equiv$

```

begin if  $cur\_l = non\_char$  then  $lft\_hit \leftarrow true$ ;
if  $j = n$  then
  if  $lig\_stack = null$  then  $rt\_hit \leftarrow true$ ;
  check\_interrupt; { allow a way out in case there's an infinite ligature loop }
  case  $op\_byte(q)$  of
     $qi(1), qi(5)$ : begin  $cur\_l \leftarrow rem\_byte(q)$ ; {  $=: |, =: |>$  }
       $ligature\_present \leftarrow true$ ;
    end;
     $qi(2), qi(6)$ : begin  $cur\_r \leftarrow rem\_byte(q)$ ; {  $|=: , |=: >$  }
      if  $lig\_stack > null$  then  $character(lig\_stack) \leftarrow cur\_r$ 
      else begin  $lig\_stack \leftarrow new\_lig\_item(cur\_r)$ ;
        if  $j = n$  then  $bchar \leftarrow non\_char$ 
        else begin  $p \leftarrow get\_avail$ ;  $lig\_ptr(lig\_stack) \leftarrow p$ ;  $character(p) \leftarrow qi(hu[j + 1])$ ;  $font(p) \leftarrow hf$ ;
          end;
        end;
      end;
     $qi(3)$ : begin  $cur\_r \leftarrow rem\_byte(q)$ ; {  $|=: |$  }
       $p \leftarrow lig\_stack$ ;  $lig\_stack \leftarrow new\_lig\_item(cur\_r)$ ;  $link(lig\_stack) \leftarrow p$ ;
    end;
     $qi(7), qi(11)$ : begin  $wrap\_lig(false)$ ; {  $|=: |>, |=: |>>$  }
       $cur\_q \leftarrow t$ ;  $cur\_l \leftarrow rem\_byte(q)$ ;  $ligature\_present \leftarrow true$ ;
    end;
  othercases begin  $cur\_l \leftarrow rem\_byte(q)$ ;  $ligature\_present \leftarrow true$ ; {  $=: \}$ 
    if  $lig\_stack > null$  then  $pop\_lig\_stack$ 
    else if  $j = n$  then goto done
    else begin  $append\_charnode\_to\_t(cur\_r)$ ;  $incr(j)$ ;  $set\_cur\_r$ ;
      end;
    end
  endcases;
  if  $op\_byte(q) > qi(4)$  then
    if  $op\_byte(q) \neq qi(7)$  then goto done;
  goto continue;
end

```

This code is used in section 1084.

1087. Okay, we're ready to insert the potential hyphenations that were found. When the following program is executed, we want to append the word $hu[1 \dots hn]$ after node ha , and node q should be appended to the result. During this process, the variable i will be a temporary index into hu ; the variable j will be an index to our current position in hu ; the variable l will be the counterpart of j , in a discretionary branch; the variable r will point to new nodes being created; and we need a few new local variables:

\langle Local variables for hyphenation 1076 $\rangle + \equiv$

```

major\_tail, minor\_tail: pointer;
  { the end of lists in the main and discretionary branches being reconstructed }
c: ASCII\_code; { character temporarily replaced by a hyphen }
c\_loc: 0 .. 63; { where that character came from }
r\_count: integer; { replacement count for discretionary }
hyf\_node: pointer; { the hyphen, if it exists }

```

1088. When the following code is performed, $hyf[0]$ and $hyf[hn]$ will be zero.

⟨ Reconstitute nodes for the hyphenated word, inserting discretionary hyphens [1088](#) ⟩ ≡

```

repeat  $l \leftarrow j$ ;  $j \leftarrow reconstitute(j, hn, bchar, qi(hyf\_char)) + 1$ ;
  if  $hyphen\_passed = 0$  then
    begin  $link(s) \leftarrow link(hold\_head)$ ;
    while  $link(s) > null$  do  $s \leftarrow link(s)$ ;
    if  $odd(hyf[j - 1])$  then
      begin  $l \leftarrow j$ ;  $hyphen\_passed \leftarrow j - 1$ ;  $link(hold\_head) \leftarrow null$ ;
      end;
    end;
  if  $hyphen\_passed > 0$  then ⟨ Create and append a discretionary node as an alternative to the
    unhyphenated word, and continue to develop both branches until they become equivalent 1089 ⟩;
until  $j > hn$ ;
 $link(s) \leftarrow q$ 

```

This code is used in section [1078](#).

1089. In this repeat loop we will insert another discretionary if $hyf[j - 1]$ is odd, when both branches of the previous discretionary end at position $j - 1$. Strictly speaking, we aren't justified in doing this, because we don't know that a hyphen after $j - 1$ is truly independent of those branches. But in almost all applications we would rather not lose a potentially valuable hyphenation point. (Consider the word 'difficult', where the letter 'c' is in position j .)

```

define  $advance\_major\_tail \equiv$ 
  begin  $major\_tail \leftarrow link(major\_tail)$ ;  $incr(r\_count)$ ;
  end

```

⟨ Create and append a discretionary node as an alternative to the unhyphenated word, and continue to develop both branches until they become equivalent [1089](#) ⟩ ≡

```

repeat  $r \leftarrow get\_node(small\_node\_size)$ ;  $link(r) \leftarrow link(hold\_head)$ ;  $type(r) \leftarrow disc\_node$ ;
   $major\_tail \leftarrow r$ ;  $r\_count \leftarrow 0$ ;
  while  $link(major\_tail) > null$  do  $advance\_major\_tail$ ;
   $i \leftarrow hyphen\_passed$ ;  $hyf[i] \leftarrow 0$ ; ⟨ Put the characters  $hu[l \dots i]$  and a hyphen into  $pre\_break(r)$  1090 ⟩;
  ⟨ Put the characters  $hu[i + 1 \dots ]$  into  $post\_break(r)$ , appending to this list and to  $major\_tail$  until
    synchronization has been achieved 1091 ⟩;
  ⟨ Move pointer  $s$  to the end of the current list, and set  $replace\_count(r)$  appropriately 1093 ⟩;
   $hyphen\_passed \leftarrow j - 1$ ;  $link(hold\_head) \leftarrow null$ ;
until  $\neg odd(hyf[j - 1])$ 

```

This code is used in section [1088](#).

1090. The new hyphen might combine with the previous character via ligature or kern. At this point we have $l - 1 \leq i < j$ and $i < hn$.

```

⟨Put the characters  $hu[l \dots i]$  and a hyphen into  $pre\_break(r)$  1090⟩ ≡
   $minor\_tail \leftarrow null$ ;  $pre\_break(r) \leftarrow null$ ;  $hyf\_node \leftarrow new\_character(hf, hyf\_char)$ ;
  if  $hyf\_node \neq null$  then
    begin  $incr(i)$ ;  $c \leftarrow hu[i]$ ;  $hu[i] \leftarrow hyf\_char$ ;  $free\_avail(hyf\_node)$ ;
    end;
  while  $l \leq i$  do
    begin  $l \leftarrow reconstitute(l, i, font\_bchar[hf], non\_char) + 1$ ;
    if  $link(hold\_head) > null$  then
      begin if  $minor\_tail = null$  then  $pre\_break(r) \leftarrow link(hold\_head)$ 
      else  $link(minor\_tail) \leftarrow link(hold\_head)$ ;
       $minor\_tail \leftarrow link(hold\_head)$ ;
      while  $link(minor\_tail) > null$  do  $minor\_tail \leftarrow link(minor\_tail)$ ;
      end;
    end;
  if  $hyf\_node \neq null$  then
    begin  $hu[i] \leftarrow c$ ; { restore the character in the hyphen position }
     $l \leftarrow i$ ;  $decr(i)$ ;
    end

```

This code is used in section 1089.

1091. The synchronization algorithm begins with $l = i + 1 \leq j$.

```

⟨Put the characters  $hu[i + 1 \dots j]$  into  $post\_break(r)$ , appending to this list and to  $major\_tail$  until
  synchronization has been achieved 1091⟩ ≡
   $minor\_tail \leftarrow null$ ;  $post\_break(r) \leftarrow null$ ;  $c\_loc \leftarrow 0$ ;
  if  $bchar\_label[hf] \neq non\_address$  then { put left boundary at beginning of new line }
    begin  $decr(l)$ ;  $c \leftarrow hu[l]$ ;  $c\_loc \leftarrow l$ ;  $hu[l] \leftarrow 256$ ;
    end;
  while  $l < j$  do
    begin repeat  $l \leftarrow reconstitute(l, hn, bchar, non\_char) + 1$ ;
    if  $c\_loc > 0$  then
      begin  $hu[c\_loc] \leftarrow c$ ;  $c\_loc \leftarrow 0$ ;
      end;
    if  $link(hold\_head) > null$  then
      begin if  $minor\_tail = null$  then  $post\_break(r) \leftarrow link(hold\_head)$ 
      else  $link(minor\_tail) \leftarrow link(hold\_head)$ ;
       $minor\_tail \leftarrow link(hold\_head)$ ;
      while  $link(minor\_tail) > null$  do  $minor\_tail \leftarrow link(minor\_tail)$ ;
      end;
    until  $l \geq j$ ;
    while  $l > j$  do ⟨Append characters of  $hu[j \dots l]$  to  $major\_tail$ , advancing  $j$  1092⟩;
    end

```

This code is used in section 1089.

```

1092. ⟨Append characters of  $hu[j \dots l]$  to  $major\_tail$ , advancing  $j$  1092⟩ ≡
  begin  $j \leftarrow reconstitute(j, hn, bchar, non\_char) + 1$ ;  $link(major\_tail) \leftarrow link(hold\_head)$ ;
  while  $link(major\_tail) > null$  do advance  $major\_tail$ ;
  end

```

This code is used in section 1091.

1093. Ligature insertion can cause a word to grow exponentially in size. Therefore we must test the size of *r_count* here, even though the hyphenated text was at most 63 characters long.

⟨ Move pointer *s* to the end of the current list, and set *replace_count*(*r*) appropriately 1093 ⟩ ≡

if *r_count* > 127 **then** { we have to forget the discretionary hyphen }

begin *link*(*s*) ← *link*(*r*); *link*(*r*) ← *null*; *flush_node_list*(*r*);

end

else begin *link*(*s*) ← *r*; *replace_count*(*r*) ← *r_count*;

end;

s ← *major_tail*

This code is used in section 1089.

1094. Hyphenation. When a word $hc[1 \dots hn]$ has been set up to contain a candidate for hyphenation, \TeX first looks to see if it is in the user’s exception dictionary. If not, hyphens are inserted based on patterns that appear within the given word, using an algorithm due to Frank M. Liang.

Let’s consider Liang’s method first, since it is much more interesting than the exception-lookup routine. The algorithm begins by setting $hyf[j]$ to zero for all j , and invalid characters are inserted into $hc[0]$ and $hc[hn+1]$ to serve as delimiters. Then a reasonably fast method is used to see which of a given set of patterns occurs in the word $hc[0 \dots (hn+1)]$. Each pattern $p_1 \dots p_k$ of length k has an associated sequence of $k+1$ numbers $n_0 \dots n_k$; and if the pattern occurs in $hc[(j+1) \dots (j+k)]$, \TeX will set $hyf[j+i] \leftarrow \max(hyf[j+i], n_i)$ for $0 \leq i \leq k$. After this has been done for each pattern that occurs, a discretionary hyphen will be inserted between $hc[j]$ and $hc[j+1]$ when $hyf[j]$ is odd, as we have already seen.

The set of patterns $p_1 \dots p_k$ and associated numbers $n_0 \dots n_k$ depends, of course, on the language whose words are being hyphenated, and on the degree of hyphenation that is desired. A method for finding appropriate p ’s and n ’s, from a given dictionary of words and acceptable hyphenations, is discussed in Liang’s Ph.D. thesis (Stanford University, 1983); \TeX simply starts with the patterns and works from there.

1095. The patterns are stored in a compact table that is also efficient for retrieval, using a variant of “trie memory” [cf. *The Art of Computer Programming* **3** (1973), 481–505]. We can find each pattern $p_1 \dots p_k$ by letting z_0 be one greater than the relevant language index and then, for $1 \leq i \leq k$, setting $z_i \leftarrow \text{trie_link}(z_{i-1}) + p_i$; the pattern will be identified by the number z_k . Since all the pattern information is packed together into a single *trie.link* array, it is necessary to prevent confusion between the data from inequivalent patterns, so another table is provided such that $\text{trie_char}(z_i) = p_i$ for all i . There is also a table $\text{trie_op}(z_k)$ to identify the numbers $n_0 \dots n_k$ associated with $p_1 \dots p_k$.

Comparatively few different number sequences $n_0 \dots n_k$ actually occur, since most of the n ’s are generally zero. Therefore the number sequences are encoded in such a way that $\text{trie_op}(z_k)$ is only one byte long. If $\text{trie_op}(z_k) \neq \text{min_quarterword}$, when $p_1 \dots p_k$ has matched the letters in $hc[(l-k+1) \dots l]$ of language t , we perform all of the required operations for this pattern by carrying out the following little program: Set $v \leftarrow \text{trie_op}(z_k)$. Then set $v \leftarrow v + \text{op_start}[t]$, $hyf[l - hyf_distance[v]] \leftarrow \max(hyf[l - hyf_distance[v]], hyf_num[v])$, and $v \leftarrow hyf_next[v]$; repeat, if necessary, until $v = \text{min_quarterword}$.

$\langle \text{Types in the outer block 18} \rangle + \equiv$

$\text{trie_pointer} = 0 \dots \text{trie_size}$; { an index into *trie* }

1096. define $\text{trie_link}(\#) \equiv \text{trie}[\#].rh$ { “downward” link in a trie }

define $\text{trie_char}(\#) \equiv \text{trie}[\#].b1$ { character matched at this trie location }

define $\text{trie_op}(\#) \equiv \text{trie}[\#].b0$ { program for hyphenation at this trie location }

$\langle \text{Global variables 13} \rangle + \equiv$

trie: **array** [*trie_pointer*] **of** *two_halves*; { *trie_link*, *trie_char*, *trie_op* }

hyf_distance: **array** [$1 \dots \text{trie_op_size}$] **of** *small_number*; { position $k - j$ of n_j }

hyf_num: **array** [$1 \dots \text{trie_op_size}$] **of** *small_number*; { value of n_j }

hyf_next: **array** [$1 \dots \text{trie_op_size}$] **of** *quarterword*; { continuation code }

op_start: **array** [*ASCII_code*] **of** $0 \dots \text{trie_op_size}$; { offset for current language }

1097. $\langle \text{Local variables for hyphenation 1076} \rangle + \equiv$

z: *trie_pointer*; { an index into *trie* }

v: *integer*; { an index into *hyf_distance*, etc. }

1098. Assuming that these auxiliary tables have been set up properly, the hyphenation algorithm is quite short. In the following code we set $hc[hn + 2]$ to the impossible value 256, in order to guarantee that $hc[hn + 3]$ will never be fetched.

```

⟨Find hyphen locations for the word in  $hc$ , or return 1098⟩ ≡
  for  $j \leftarrow 0$  to  $hn$  do  $hyf[j] \leftarrow 0$ ;
  ⟨Look for the word  $hc[1 \dots hn]$  in the exception table, and goto found (with  $hyf$  containing the hyphens)
    if an entry is found 1105);
  if  $trie\_char(cur\_lang + 1) \neq qi(cur\_lang)$  then return; {no patterns for  $cur\_lang$ }
   $hc[0] \leftarrow 0$ ;  $hc[hn + 1] \leftarrow 0$ ;  $hc[hn + 2] \leftarrow 256$ ; {insert delimiters}
  for  $j \leftarrow 0$  to  $hn - r\_hyf + 1$  do
    begin  $z \leftarrow trie\_link(cur\_lang + 1) + hc[j]$ ;  $l \leftarrow j$ ;
    while  $hc[l] = qo(trie\_char(z))$  do
      begin if  $trie\_op(z) \neq min\_quarterword$  then ⟨Store maximum values in the  $hyf$  table 1099⟩;
       $incr(l)$ ;  $z \leftarrow trie\_link(z) + hc[l]$ ;
    end;
  end;
found: for  $j \leftarrow 0$  to  $l\_hyf - 1$  do  $hyf[j] \leftarrow 0$ ;
  for  $j \leftarrow 0$  to  $r\_hyf - 1$  do  $hyf[hn - j] \leftarrow 0$ 

```

This code is used in section 1070.

```

1099. ⟨Store maximum values in the  $hyf$  table 1099⟩ ≡
  begin  $v \leftarrow trie\_op(z)$ ;
  repeat  $v \leftarrow v + op\_start[cur\_lang]$ ;  $i \leftarrow l - hyf\_distance[v]$ ;
    if  $hyf\_num[v] > hyf[i]$  then  $hyf[i] \leftarrow hyf\_num[v]$ ;
     $v \leftarrow hyf\_next[v]$ ;
  until  $v = min\_quarterword$ ;
  end

```

This code is used in section 1098.

1100. The exception table that is built by TeX's `\hyphenation` primitive is organized as an ordered hash table [cf. Amble and Knuth, *The Computer Journal* **17** (1974), 135–142] using linear probing. If α and β are words, we will say that $\alpha < \beta$ if $|\alpha| < |\beta|$ or if $|\alpha| = |\beta|$ and α is lexicographically smaller than β . (The notation $|\alpha|$ stands for the length of α .) The idea of ordered hashing is to arrange the table so that a given word α can be sought by computing a hash address $h = h(\alpha)$ and then looking in table positions h , $h - 1$, \dots , until encountering the first word $\leq \alpha$. If this word is different from α , we can conclude that α is not in the table.

The words in the table point to lists in *mem* that specify hyphen positions in their *info* fields. The list for $c_1 \dots c_n$ contains the number k if the word $c_1 \dots c_n$ has a discretionary hyphen between c_k and c_{k+1} .

```

⟨Types in the outer block 18⟩ +≡
   $hyph\_pointer = 0 \dots hyph\_size$ ; {an index into the ordered hash table}

```

```

1101. ⟨Global variables 13⟩ +≡
   $hyph\_word$ : array [ $hyph\_pointer$ ] of  $str\_number$ ; {exception words}
   $hyph\_list$ : array [ $hyph\_pointer$ ] of  $pointer$ ; {lists of hyphen positions}
   $hyph\_count$ :  $hyph\_pointer$ ; {the number of words in the exception dictionary}

```

```

1102. ⟨Local variables for initialization 19⟩ +≡
   $z$ :  $hyph\_pointer$ ; {runs through the exception dictionary}

```

1103. \langle Set initial values of key variables [21](#) $\rangle + \equiv$
for $z \leftarrow 0$ **to** $hyph_size$ **do**
 begin $hyph_word[z] \leftarrow 0$; $hyph_list[z] \leftarrow null$;
 end;
 $hyph_count \leftarrow 0$;

1104. The algorithm for exception lookup is quite simple, as soon as we have a few more local variables to work with.

\langle Local variables for hyphenation [1076](#) $\rangle + \equiv$
 h : $hyph_pointer$; { an index into $hyph_word$ and $hyph_list$ }
 k : str_number ; { an index into str_start }
 u : $pool_pointer$; { an index into str_pool }

1105. First we compute the hash code h , then we search until we either find the word or we don't. Words from different languages are kept separate by appending the language code to the string.

\langle Look for the word $hc[1 \dots hn]$ in the exception table, and **goto** *found* (with *hyf* containing the hyphens) if an entry is found [1105](#) $\rangle \equiv$
 $h \leftarrow hc[1]$; $incr(hn)$; $hc[hn] \leftarrow cur_lang$;
for $j \leftarrow 2$ **to** hn **do** $h \leftarrow (h + h + hc[j]) \bmod hyph_size$;
loop begin \langle If the string $hyph_word[h]$ is less than $hc[1 \dots hn]$, **goto** *not_found*; but if the two strings are equal, set *hyf* to the hyphen positions and **goto** *found* [1106](#) \rangle ;
 if $h > 0$ **then** $decr(h)$ **else** $h \leftarrow hyph_size$;
 end;
not_found: $decr(hn)$

This code is used in section [1098](#).

1106. \langle If the string $hyph_word[h]$ is less than $hc[1 \dots hn]$, **goto** *not_found*; but if the two strings are equal, set *hyf* to the hyphen positions and **goto** *found* [1106](#) $\rangle \equiv$
 $k \leftarrow hyph_word[h]$;
if $k = 0$ **then** **goto** *not_found*;
if $length(k) < hn$ **then** **goto** *not_found*;
if $length(k) = hn$ **then**
 begin $j \leftarrow 1$; $u \leftarrow str_start[k]$;
 repeat if $so(str_pool[u]) < hc[j]$ **then** **goto** *not_found*;
 if $so(str_pool[u]) > hc[j]$ **then** **goto** *done*;
 $incr(j)$; $incr(u)$;
 until $j > hn$;
 \langle Insert hyphens as specified in $hyph_list[h]$ [1107](#) \rangle ;
 $decr(hn)$; **goto** *found*;
 end;
done:

This code is used in section [1105](#).

1107. \langle Insert hyphens as specified in $hyph_list[h]$ [1107](#) $\rangle \equiv$
 $s \leftarrow hyph_list[h]$;
while $s \neq null$ **do**
 begin $hyf[info(s)] \leftarrow 1$; $s \leftarrow link(s)$;
 end

This code is used in section [1106](#).

```

1108.  ⟨ Search hyph_list for pointers to p 1108 ⟩ ≡
  for q ← 0 to hyph_size do
    begin if hyph_list[q] = p then
      begin print_nl("HYPH("); print_int(q); print_char(")");
      end;
    end
  end

```

This code is used in section 190.

1109. We have now completed the hyphenation routine, so the *line_break* procedure is finished at last. Since the hyphenation exception table is fresh in our minds, it's a good time to deal with the routine that adds new entries to it.

When TeX has scanned ‘\hyphenation’, it calls on a procedure named *new_hyph_exceptions* to do the right thing.

```

define set_cur_lang ≡
  if language ≤ 0 then cur_lang ← 0
  else if language > 255 then cur_lang ← 0
  else cur_lang ← language
procedure new_hyph_exceptions; { enters new exceptions }
label reswitch, exit, found, not_found, not_found1;
var n: 0 .. 64; { length of current word; not always a small_number }
    j: 0 .. 64; { an index into hc }
    h: hyph_pointer; { an index into hyph_word and hyph_list }
    k: str_number; { an index into str_start }
    p: pointer; { head of a list of hyphen positions }
    q: pointer; { used when creating a new node for list p }
    s, t: str_number; { strings being compared or stored }
    u, v: pool_pointer; { indices into str_pool }
begin scan_left_brace; { a left brace must follow \hyphenation }
set_cur_lang;
init if trie_not_ready then
  begin hyph_index ← 0; goto not_found1;
  end;
tini
  set_hyph_index;
not_found1: ⟨ Enter as many hyphenation exceptions as are listed, until coming to a right brace; then
  return 1110 ⟩;
exit: end;

```

1110. \langle Enter as many hyphenation exceptions as are listed, until coming to a right brace; then **return** 1110 $\rangle \equiv$

```

n  $\leftarrow$  0; p  $\leftarrow$  null;
loop begin get_x_token;
reswitch: case cur_cmd of
  letter, other_char, char_given:  $\langle$  Append a new letter or hyphen 1112  $\rangle$ ;
  char_num: begin scan_char_num; cur_chr  $\leftarrow$  cur_val; cur_cmd  $\leftarrow$  char_given; goto reswitch;
  end;
  spacer, right_brace: begin if n > 1 then  $\langle$  Enter a hyphenation exception 1114  $\rangle$ ;
    if cur_cmd = right_brace then return;
    n  $\leftarrow$  0; p  $\leftarrow$  null;
  end;
  othercases  $\langle$  Give improper \hyphenation error 1111  $\rangle$ 
endcases;
end

```

This code is used in section 1109.

1111. \langle Give improper \hyphenation error 1111 $\rangle \equiv$

```

begin print_err("Improper_"); print_esc("hyphenation"); print("_will_be_flushed");
help2("Hyphenation_exceptions_must_contain_only_letters")
("and_hyphens._But_continue;_I'll_forgive_and_forget."); error;
end

```

This code is used in section 1110.

1112. \langle Append a new letter or hyphen 1112 $\rangle \equiv$

```

if cur_chr = "-" then  $\langle$  Append the value n to list p 1113  $\rangle$ 
else begin set_lc_code(cur_chr);
  if hc[0] = 0 then
    begin print_err("Not_a_letter");
    help2("Letters_in_\hyphenation_words_must_have_\lccode>0.")
    ("Proceed;_I'll_ignore_the_character_I_just_read."); error;
    end
  else if n < 63 then
    begin incr(n); hc[n]  $\leftarrow$  hc[0];
    end;
  end

```

This code is used in section 1110.

1113. \langle Append the value *n* to list *p* 1113 $\rangle \equiv$

```

begin if n < 63 then
  begin q  $\leftarrow$  get_avail; link(q)  $\leftarrow$  p; info(q)  $\leftarrow$  n; p  $\leftarrow$  q;
  end;
end

```

This code is used in section 1112.

1114. $\langle \text{Enter a hyphenation exception 1114} \rangle \equiv$
begin $\text{incr}(n)$; $\text{hc}[n] \leftarrow \text{cur_lang}$; $\text{str_room}(n)$; $h \leftarrow 0$;
for $j \leftarrow 1$ **to** n **do**
 begin $h \leftarrow (h + h + \text{hc}[j]) \bmod \text{hyph_size}$; $\text{append_char}(\text{hc}[j])$;
 end;
 $s \leftarrow \text{make_string}$; $\langle \text{Insert the pair } (s, p) \text{ into the exception table 1115} \rangle$;
end

This code is used in section 1110.

1115. $\langle \text{Insert the pair } (s, p) \text{ into the exception table 1115} \rangle \equiv$
if $\text{hyph_count} = \text{hyph_size}$ **then** $\text{overflow}(\text{"exception_dictionary"}, \text{hyph_size})$;
 $\text{incr}(\text{hyph_count})$;
while $\text{hyph_word}[h] \neq 0$ **do**
 begin $\langle \text{If the string } \text{hyph_word}[h] \text{ is less than or equal to } s, \text{ interchange } (\text{hyph_word}[h], \text{hyph_list}[h])$
 with (s, p) 1116 \rangle ;
 if $h > 0$ **then** $\text{decr}(h)$ **else** $h \leftarrow \text{hyph_size}$;
 end;
 $\text{hyph_word}[h] \leftarrow s$; $\text{hyph_list}[h] \leftarrow p$

This code is used in section 1114.

1116. $\langle \text{If the string } \text{hyph_word}[h] \text{ is less than or equal to } s, \text{ interchange } (\text{hyph_word}[h], \text{hyph_list}[h]) \text{ with } (s, p)$ 1116 $\rangle \equiv$
 $k \leftarrow \text{hyph_word}[h]$;
if $\text{length}(k) < \text{length}(s)$ **then** **goto** found ;
if $\text{length}(k) > \text{length}(s)$ **then** **goto** not_found ;
 $u \leftarrow \text{str_start}[k]$; $v \leftarrow \text{str_start}[s]$;
repeat **if** $\text{str_pool}[u] < \text{str_pool}[v]$ **then** **goto** found ;
 if $\text{str_pool}[u] > \text{str_pool}[v]$ **then** **goto** not_found ;
 $\text{incr}(u)$; $\text{incr}(v)$;
until $u = \text{str_start}[k + 1]$;
 found : $q \leftarrow \text{hyph_list}[h]$; $\text{hyph_list}[h] \leftarrow p$; $p \leftarrow q$;
 $t \leftarrow \text{hyph_word}[h]$; $\text{hyph_word}[h] \leftarrow s$; $s \leftarrow t$;
 not_found :

This code is used in section 1115.

1117. Initializing the hyphenation tables. The trie for T_EX’s hyphenation algorithm is built from a sequence of patterns following a `\patterns` specification. Such a specification is allowed only in `INITEX`, since the extra memory for auxiliary tables and for the initialization program itself would only clutter up the production version of T_EX with a lot of deadwood.

The first step is to build a trie that is linked, instead of packed into sequential storage, so that insertions are readily made. After all patterns have been processed, `INITEX` compresses the linked trie by identifying common subtrees. Finally the trie is packed into the efficient sequential form that the hyphenation algorithm actually uses.

```

⟨ Declare subprocedures for line_break 1000 ⟩ +≡
  init ⟨ Declare procedures for preprocessing hyphenation patterns 1119 ⟩
tini

```

1118. Before we discuss trie building in detail, let’s consider the simpler problem of creating the *hyf_distance*, *hyf_num*, and *hyf_next* arrays.

Suppose, for example, that T_EX reads the pattern ‘`ab2cde1`’. This is a pattern of length 5, with $n_0 \dots n_5 = 002001$ in the notation above. We want the corresponding *trie_op* code v to have $hyf_distance[v] = 3$, $hyf_num[v] = 2$, and $hyf_next[v] = v'$, where the auxiliary *trie_op* code v' has $hyf_distance[v'] = 0$, $hyf_num[v'] = 1$, and $hyf_next[v'] = min_quarterword$.

T_EX computes an appropriate value v with the *new_trie_op* subroutine below, by setting

$$v' \leftarrow new_trie_op(0, 1, min_quarterword), \quad v \leftarrow new_trie_op(3, 2, v').$$

This subroutine looks up its three parameters in a special hash table, assigning a new value only if these three have not appeared before for the current language.

The hash table is called *trie_op_hash*, and the number of entries it contains is *trie_op_ptr*.

```

⟨ Global variables 13 ⟩ +≡
  init trie_op_hash: array [ $-trie\_op\_size \dots trie\_op\_size$ ] of  $0 \dots trie\_op\_size$ ;
    { trie op codes for quadruples }
trie_used: array [ASCII_code] of quarterword; { largest opcode used so far for this language }
trie_op_lang: array [ $1 \dots trie\_op\_size$ ] of ASCII_code; { language part of a hashed quadruple }
trie_op_val: array [ $1 \dots trie\_op\_size$ ] of quarterword; { opcode corresponding to a hashed quadruple }
trie_op_ptr:  $0 \dots trie\_op\_size$ ; { number of stored ops so far }
tini

```


1119. It's tempting to remove the *overflow* stops in the following procedure; *new_trie_op* could return *min_quarterword* (thereby simply ignoring part of a hyphenation pattern) instead of aborting the job. However, that would lead to different hyphenation results on different installations of TeX using the same patterns. The *overflow* stops are necessary for portability of patterns.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ ≡

```
function new_trie_op(d, n : small_number; v : quarterword): quarterword;
  label exit;
  var h:  $-trie\_op\_size \dots trie\_op\_size$ ; { trial hash location }
      u: quarterword; { trial op code }
      l:  $0 \dots trie\_op\_size$ ; { pointer to stored data }
  begin h  $\leftarrow abs(n + 313 * d + 361 * v + 1009 * cur\_lang) \bmod (trie\_op\_size + trie\_op\_size) - trie\_op\_size$ ;
  loop begin l  $\leftarrow trie\_op\_hash[h]$ ;
    if l = 0 then { empty position found for a new op }
      begin if trie_op_ptr = trie_op_size then overflow("pattern_memory_ops", trie_op_size);
        u  $\leftarrow trie\_used[cur\_lang]$ ;
        if u = max_quarterword then
          overflow("pattern_memory_ops_per_language", max_quarterword - min_quarterword);
          incr(trie_op_ptr); incr(u); trie_used[cur_lang]  $\leftarrow u$ ; hyf_distance[trie_op_ptr]  $\leftarrow d$ ;
          hyf_num[trie_op_ptr]  $\leftarrow n$ ; hyf_next[trie_op_ptr]  $\leftarrow v$ ; trie_op_lang[trie_op_ptr]  $\leftarrow cur\_lang$ ;
          trie_op_hash[h]  $\leftarrow trie\_op\_ptr$ ; trie_op_val[trie_op_ptr]  $\leftarrow u$ ; new_trie_op  $\leftarrow u$ ; return;
        end;
      if (hyf_distance[l] = d)  $\wedge$  (hyf_num[l] = n)  $\wedge$  (hyf_next[l] = v)  $\wedge$  (trie_op_lang[l] = cur_lang) then
        begin new_trie_op  $\leftarrow trie\_op\_val[l]$ ; return;
        end;
      if h >  $-trie\_op\_size$  then decr(h) else h  $\leftarrow trie\_op\_size$ ;
      end;
  exit: end;
```

See also sections 1123, 1124, 1128, 1132, 1134, 1135, and 1141.

This code is used in section 1117.

1120. After *new_trie_op* has compressed the necessary opcode information, plenty of information is available to unscramble the data into the final form needed by our hyphenation algorithm.

⟨Sort the hyphenation op tables into proper order 1120⟩ ≡

```
op_start[0]  $\leftarrow -min\_quarterword$ ;
for j  $\leftarrow 1$  to 255 do op_start[j]  $\leftarrow op\_start[j - 1] + qo(trie\_used[j - 1])$ ;
for j  $\leftarrow 1$  to trie_op_ptr do trie_op_hash[j]  $\leftarrow op\_start[trie\_op\_lang[j]] + trie\_op\_val[j]$ ; { destination }
for j  $\leftarrow 1$  to trie_op_ptr do
  while trie_op_hash[j] > j do
    begin k  $\leftarrow trie\_op\_hash[j]$ ;
      t  $\leftarrow hyf\_distance[k]$ ; hyf_distance[k]  $\leftarrow hyf\_distance[j]$ ; hyf_distance[j]  $\leftarrow t$ ;
      t  $\leftarrow hyf\_num[k]$ ; hyf_num[k]  $\leftarrow hyf\_num[j]$ ; hyf_num[j]  $\leftarrow t$ ;
      t  $\leftarrow hyf\_next[k]$ ; hyf_next[k]  $\leftarrow hyf\_next[j]$ ; hyf_next[j]  $\leftarrow t$ ;
      trie_op_hash[j]  $\leftarrow trie\_op\_hash[k]$ ; trie_op_hash[k]  $\leftarrow j$ ;
    end
```

This code is used in section 1127.

1121. Before we forget how to initialize the data structures that have been mentioned so far, let's write down the code that gets them started.

```

<Initialize table entries (done by INITEX only) 182> +≡
  for  $k \leftarrow -trie\_op\_size$  to  $trie\_op\_size$  do  $trie\_op\_hash[k] \leftarrow 0$ ;
  for  $k \leftarrow 0$  to 255 do  $trie\_used[k] \leftarrow min\_quarterword$ ;
   $trie\_op\_ptr \leftarrow 0$ ;

```

1122. The linked trie that is used to preprocess hyphenation patterns appears in several global arrays. Each node represents an instruction of the form “if you see character c , then perform operation o , move to the next character, and go to node l ; otherwise go to node r .” The four quantities c , o , l , and r are stored in four arrays $trie_c$, $trie_o$, $trie_l$, and $trie_r$. The root of the trie is $trie_l[0]$, and the number of nodes is $trie_ptr$. Null trie pointers are represented by zero. To initialize the trie, we simply set $trie_l[0]$ and $trie_ptr$ to zero. We also set $trie_c[0]$ to some arbitrary value, since the algorithm may access it.

The algorithms maintain the condition

$$trie_c[trie_r[z]] > trie_c[z] \quad \text{whenever } z \neq 0 \text{ and } trie_r[z] \neq 0;$$

in other words, sibling nodes are ordered by their c fields.

define $trie_root \equiv trie_l[0]$ { root of the linked trie }

<Global variables 13> +≡

```

init  $trie\_c$ : packed array [ $trie\_pointer$ ] of  $packed\_ASCII\_code$ ; { characters to match }
 $trie\_o$ : packed array [ $trie\_pointer$ ] of  $quarterword$ ; { operations to perform }
 $trie\_l$ : packed array [ $trie\_pointer$ ] of  $trie\_pointer$ ; { left subtrie links }
 $trie\_r$ : packed array [ $trie\_pointer$ ] of  $trie\_pointer$ ; { right subtrie links }
 $trie\_ptr$ :  $trie\_pointer$ ; { the number of nodes in the trie }
 $trie\_hash$ : packed array [ $trie\_pointer$ ] of  $trie\_pointer$ ; { used to identify equivalent subtrees }
tini

```

1123. Let us suppose that a linked trie has already been constructed. Experience shows that we can often reduce its size by recognizing common subtrees; therefore another hash table is introduced for this purpose, somewhat similar to $trie_op_hash$. The new hash table will be initialized to zero.

The function $trie_node(p)$ returns p if p is distinct from other nodes that it has seen, otherwise it returns the number of the first equivalent node that it has seen.

Notice that we might make subtrees equivalent even if they correspond to patterns for different languages, in which the trie ops might mean quite different things. That's perfectly all right.

<Declare procedures for preprocessing hyphenation patterns 1119> +≡

```

function  $trie\_node(p : trie\_pointer)$ :  $trie\_pointer$ ; { converts to a canonical form }
  label  $exit$ ;
  var  $h$ :  $trie\_pointer$ ; { trial hash location }
   $q$ :  $trie\_pointer$ ; { trial trie node }
  begin  $h \leftarrow abs(trie\_c[p] + 1009 * trie\_o[p] + 2718 * trie\_l[p] + 3142 * trie\_r[p]) \bmod trie\_size$ ;
  loop begin  $q \leftarrow trie\_hash[h]$ ;
    if  $q = 0$  then
      begin  $trie\_hash[h] \leftarrow p$ ;  $trie\_node \leftarrow p$ ; return;
    end;
    if  $(trie\_c[q] = trie\_c[p]) \wedge (trie\_o[q] = trie\_o[p]) \wedge (trie\_l[q] = trie\_l[p]) \wedge (trie\_r[q] = trie\_r[p])$  then
      begin  $trie\_node \leftarrow q$ ; return;
    end;
    if  $h > 0$  then  $decr(h)$  else  $h \leftarrow trie\_size$ ;
  end;
 $exit$ : end;

```

1124. A neat recursive procedure is now able to compress a trie by traversing it and applying *trie_node* to its nodes in “bottom up” fashion. We will compress the entire trie by clearing *trie_hash* to zero and then saying ‘*trie_root* \leftarrow *compress_trie*(*trie_root*)’.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ \equiv

```
function compress_trie(p : trie_pointer): trie_pointer;
  begin if p = 0 then compress_trie  $\leftarrow$  0
  else begin trie_l[p]  $\leftarrow$  compress_trie(trie_l[p]); trie_r[p]  $\leftarrow$  compress_trie(trie_r[p]);
    compress_trie  $\leftarrow$  trie_node(p);
  end;
end;
```

1125. The compressed trie will be packed into the *trie* array using a “top-down first-fit” procedure. This is a little tricky, so the reader should pay close attention: The *trie_hash* array is cleared to zero again and renamed *trie_ref* for this phase of the operation; later on, *trie_ref*[*p*] will be nonzero only if the linked trie node *p* is the smallest character in a family and if the characters *c* of that family have been allocated to locations *trie_ref*[*p*] + *c* in the *trie* array. Locations of *trie* that are in use will have *trie_link* = 0, while the unused holes in *trie* will be doubly linked with *trie_link* pointing to the next larger vacant location and *trie_back* pointing to the next smaller one. This double linking will have been carried out only as far as *trie_max*, where *trie_max* is the largest index of *trie* that will be needed. To save time at the low end of the trie, we maintain array entries *trie_min*[*c*] pointing to the smallest hole that is greater than *c*. Another array *trie_taken* tells whether or not a given location is equal to *trie_ref*[*p*] for some *p*; this array is used to ensure that distinct nodes in the compressed trie will have distinct *trie_ref* entries.

```
define trie_ref  $\equiv$  trie_hash { where linked trie families go into trie }
define trie_back(#)  $\equiv$  trie[#].lh { backward links in trie holes }
```

⟨Global variables 13⟩ \equiv

```
init trie_taken: packed array [1 .. trie_size] of boolean; { does a family start here? }
trie_min: array [ASCII_code] of trie_pointer; { the first possible slot for each character }
trie_max: trie_pointer; { largest location used in trie }
trie_not_ready: boolean; { is the trie still in linked form? }
tini
```

1126. Each time \patterns appears, it contributes further patterns to the future trie, which will be built only when hyphenation is attempted or when a format file is dumped. The boolean variable *trie_not_ready* will change to *false* when the trie is compressed; this will disable further patterns.

⟨Initialize table entries (done by INITEX only) 182⟩ \equiv

```
trie_not_ready  $\leftarrow$  true; trie_root  $\leftarrow$  0; trie_c[0]  $\leftarrow$  si(0); trie_ptr  $\leftarrow$  0;
```

1127. Here is how the trie-compression data structures are initialized. If storage is tight, it would be possible to overlap *trie_op_hash*, *trie_op_lang*, and *trie_op_val* with *trie*, *trie_hash*, and *trie_taken*, because we finish with the former just before we need the latter.

⟨Get ready to compress the trie 1127⟩ \equiv

```
⟨Sort the hyphenation op tables into proper order 1120⟩;
for p  $\leftarrow$  0 to trie_size do trie_hash[p]  $\leftarrow$  0;
hyph_root  $\leftarrow$  compress_trie(hyph_root); trie_root  $\leftarrow$  compress_trie(trie_root);
  { identify equivalent subtries }
for p  $\leftarrow$  0 to trie_ptr do trie_ref[p]  $\leftarrow$  0;
for p  $\leftarrow$  0 to 255 do trie_min[p]  $\leftarrow$  p + 1;
trie_link(0)  $\leftarrow$  1; trie_max  $\leftarrow$  0
```

This code is used in section 1141.

1128. The *first_fit* procedure finds the smallest hole z in *trie* such that a trie family starting at a given node p will fit into vacant positions starting at z . If $c = \text{trie_c}[p]$, this means that location $z - c$ must not already be taken by some other family, and that $z - c + c'$ must be vacant for all characters c' in the family. The procedure sets $\text{trie_ref}[p]$ to $z - c$ when the first fit has been found.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ +≡

```
procedure first_fit( $p : \text{trie\_pointer}$ ); { packs a family into trie }
  label not_found, found;
  var  $h : \text{trie\_pointer}$ ; { candidate for  $\text{trie\_ref}[p]$  }
     $z : \text{trie\_pointer}$ ; { runs through holes }
     $q : \text{trie\_pointer}$ ; { runs through the family starting at  $p$  }
     $c : \text{ASCII\_code}$ ; { smallest character in the family }
     $l, r : \text{trie\_pointer}$ ; { left and right neighbors }
     $ll : 1 \dots 256$ ; { upper limit of  $\text{trie\_min}$  updating }
  begin  $c \leftarrow \text{so}(\text{trie\_c}[p])$ ;  $z \leftarrow \text{trie\_min}[c]$ ; { get the first conceivably good hole }
  loop begin  $h \leftarrow z - c$ ;
    ⟨Ensure that  $\text{trie\_max} \geq h + 256$  1129⟩;
    if  $\text{trie\_taken}[h]$  then goto not_found;
    ⟨If all characters of the family fit relative to  $h$ , then goto found, otherwise goto not_found 1130⟩;
    not_found:  $z \leftarrow \text{trie\_link}(z)$ ; { move to the next hole }
    end;
  found: ⟨Pack the family into trie relative to  $h$  1131⟩;
  end;
```

1129. By making sure that trie_max is at least $h + 256$, we can be sure that $\text{trie_max} > z$, since $h = z - c$. It follows that location trie_max will never be occupied in *trie*, and we will have $\text{trie_max} \geq \text{trie_link}(z)$.

⟨Ensure that $\text{trie_max} \geq h + 256$ 1129⟩ ≡

```
if  $\text{trie\_max} < h + 256$  then
  begin if  $\text{trie\_size} \leq h + 256$  then overflow("pattern_memory",  $\text{trie\_size}$ );
  repeat  $\text{incr}(\text{trie\_max})$ ;  $\text{trie\_taken}[\text{trie\_max}] \leftarrow \text{false}$ ;  $\text{trie\_link}(\text{trie\_max}) \leftarrow \text{trie\_max} + 1$ ;
     $\text{trie\_back}(\text{trie\_max}) \leftarrow \text{trie\_max} - 1$ ;
  until  $\text{trie\_max} = h + 256$ ;
  end
```

This code is used in section 1128.

1130. ⟨If all characters of the family fit relative to h , then **goto** *found*, otherwise **goto** *not_found* 1130⟩ ≡

```
 $q \leftarrow \text{trie\_r}[p]$ ;
while  $q > 0$  do
  begin if  $\text{trie\_link}(h + \text{so}(\text{trie\_c}[q])) = 0$  then goto not_found;
   $q \leftarrow \text{trie\_r}[q]$ ;
  end;
goto found
```

This code is used in section 1128.

1131. \langle Pack the family into *trie* relative to *h* 1131 $\rangle \equiv$
 $trie_taken[h] \leftarrow true; trie_ref[p] \leftarrow h; q \leftarrow p;$
repeat $z \leftarrow h + so(trie_c[q]); l \leftarrow trie_back(z); r \leftarrow trie_link(z); trie_back(r) \leftarrow l; trie_link(l) \leftarrow r;$
 $trie_link(z) \leftarrow 0;$
if $l < 256$ **then**
 begin if $z < 256$ **then** $ll \leftarrow z$ **else** $ll \leftarrow 256;$
 repeat $trie_min[l] \leftarrow r; incr(l);$
 until $l = ll;$
 end;
 $q \leftarrow trie_r[q];$
until $q = 0$

This code is used in section 1128.

1132. To pack the entire linked trie, we use the following recursive procedure.

\langle Declare procedures for preprocessing hyphenation patterns 1119 $\rangle + \equiv$
procedure *trie_pack*(*p* : *trie_pointer*); { pack subtries of a family }
var *q*: *trie_pointer*; { a local variable that need not be saved on recursive calls }
begin repeat $q \leftarrow trie_l[p];$
 if $(q > 0) \wedge (trie_ref[q] = 0)$ **then**
 begin *first_fit*(*q*); *trie_pack*(*q*);
 end;
 $p \leftarrow trie_r[p];$
until $p = 0;$
end;

1133. When the whole trie has been allocated into the sequential table, we must go through it once again so that *trie* contains the correct information. Null pointers in the linked trie will be represented by the value 0, which properly implements an “empty” family.

\langle Move the data into *trie* 1133 $\rangle \equiv$
 $h.rh \leftarrow 0; h.b0 \leftarrow min_quarterword; h.b1 \leftarrow min_quarterword;$
 $\{ trie_link \leftarrow 0, trie_op \leftarrow min_quarterword, trie_char \leftarrow qi(0) \}$
if $trie_max = 0$ **then** { no patterns were given }
 begin for $r \leftarrow 0$ **to** 256 **do** $trie[r] \leftarrow h;$
 $trie_max \leftarrow 256;$
 end
else begin if $hyph_root > 0$ **then** *trie_fix*(*hyph_root*);
 if $trie_root > 0$ **then** *trie_fix*(*trie_root*); { this fixes the non-holes in *trie* }
 $r \leftarrow 0;$ { now we will zero out all the holes }
 repeat $s \leftarrow trie_link(r); trie[r] \leftarrow h; r \leftarrow s;$
 until $r > trie_max;$
 end;
 $trie_char(0) \leftarrow qi("?");$ { make $trie_char(c) \neq c$ for all *c* }

This code is used in section 1141.

1134. The fixing-up procedure is, of course, recursive. Since the linked trie usually has overlapping subtries, the same data may be moved several times; but that causes no harm, and at most as much work is done as it took to build the uncompressed trie.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ +≡

```
procedure trie_fix(p : trie_pointer); { moves p and its siblings into trie }
  var q : trie_pointer; { a local variable that need not be saved on recursive calls }
      c : ASCII_code; { another one that need not be saved }
      z : trie_pointer; { trie reference; this local variable must be saved }
  begin z ← trie_ref[p];
  repeat q ← trie_l[p]; c ← so(trie_c[p]); trie_link(z + c) ← trie_ref[q]; trie_char(z + c) ← qi(c);
    trie_op(z + c) ← trie_o[p];
    if q > 0 then trie_fix(q);
    p ← trie_r[p];
  until p = 0;
end;
```

1135. Now let's go back to the easier problem, of building the linked trie. When INITEX has scanned the 'patterns' control sequence, it calls on *new_patterns* to do the right thing.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ +≡

```
procedure new_patterns; { initializes the hyphenation pattern data }
  label done, done1;
  var k, l: 0 .. 64; { indices into hc and hyf; not always in small_number range }
      digit_sensed: boolean; { should the next digit be treated as a letter? }
      v: quarterword; { trie op code }
      p, q: trie_pointer; { nodes of trie traversed during insertion }
      first_child: boolean; { is p = trie_l[q]? }
      c: ASCII_code; { character being inserted }
  begin if trie_not_ready then
    begin set_cur_lang; scan_left_brace; { a left brace must follow \patterns }
    ⟨Enter all of the patterns into a linked trie, until coming to a right brace 1136⟩;
    if saving_hyph_codes > 0 then ⟨Store hyphenation codes for current language 1852⟩;
    end
  else begin print_err("Too_late_for_"); print_esc("patterns");
    help1("All_patterns_must_be_given_before_typesetting_begins."); error;
    link(garbage) ← scan_toks(false, false); flush_list(def_ref);
    end;
  end;
```

1136. Novices are not supposed to be using `\patterns`, so the error messages are terse. (Note that all error messages appear in TeX's string pool, even if they are used only by INITEX.)

⟨ Enter all of the patterns into a linked trie, until coming to a right brace 1136 ⟩ ≡

```

  k ← 0; hyf[0] ← 0; digit_sensed ← false;
  loop begin get_x_token;
    case cur_cmd of
      letter, other_char: ⟨ Append a new letter or a hyphen level 1137 ⟩;
      spacer, right_brace: begin if k > 0 then ⟨ Insert a new pattern into the linked trie 1138 ⟩;
        if cur_cmd = right_brace then goto done;
        k ← 0; hyf[0] ← 0; digit_sensed ← false;
      end;
    othercases begin print_err("Bad_"); print_esc("patterns"); help1("(See_␣Appendix_␣H.)"); error;
    end
  endcases;
end;
done:

```

This code is used in section 1135.

1137. ⟨ Append a new letter or a hyphen level 1137 ⟩ ≡

```

  if digit_sensed ∨ (cur_chr < "0") ∨ (cur_chr > "9") then
    begin if cur_chr = "." then cur_chr ← 0 { edge-of-word delimiter }
    else begin cur_chr ← lc_code(cur_chr);
      if cur_chr = 0 then
        begin print_err("Nonletter"); help1("(See_␣Appendix_␣H.)"); error;
      end;
    end;
  if k < 63 then
    begin incr(k); hc[k] ← cur_chr; hyf[k] ← 0; digit_sensed ← false;
    end;
  end
  else if k < 63 then
    begin hyf[k] ← cur_chr - "0"; digit_sensed ← true;
    end
  end

```

This code is used in section 1136.

1138. When the following code comes into play, the pattern $p_1 \dots p_k$ appears in $hc[1 \dots k]$, and the corresponding sequence of numbers $n_0 \dots n_k$ appears in $hyf[0 \dots k]$.

```

⟨Insert a new pattern into the linked trie 1138⟩ ≡
  begin ⟨Compute the trie op code,  $v$ , and set  $l \leftarrow 0$  1140⟩;
   $q \leftarrow 0$ ;  $hc[0] \leftarrow cur\_lang$ ;
  while  $l \leq k$  do
    begin  $c \leftarrow hc[l]$ ;  $incr(l)$ ;  $p \leftarrow trie\_l[q]$ ;  $first\_child \leftarrow true$ ;
    while  $(p > 0) \wedge (c > so(trie\_c[p]))$  do
      begin  $q \leftarrow p$ ;  $p \leftarrow trie\_r[q]$ ;  $first\_child \leftarrow false$ ;
      end;
    if  $(p = 0) \vee (c < so(trie\_c[p]))$  then
      ⟨Insert a new trie node between  $q$  and  $p$ , and make  $p$  point to it 1139⟩;
       $q \leftarrow p$ ; { now node  $q$  represents  $p_1 \dots p_{l-1}$  }
    end;
  if  $trie\_o[q] \neq min\_quarterword$  then
    begin  $print\_err("Duplicate\_pattern")$ ;  $help1("(\text{See\_Appendix\_H.})")$ ;  $error$ ;
    end;
   $trie\_o[q] \leftarrow v$ ;
end

```

This code is used in section 1136.

```

1139. ⟨Insert a new trie node between  $q$  and  $p$ , and make  $p$  point to it 1139⟩ ≡
  begin if  $trie\_ptr = trie\_size$  then  $overflow("pattern\_memory", trie\_size)$ ;
   $incr(trie\_ptr)$ ;  $trie\_r[trie\_ptr] \leftarrow p$ ;  $p \leftarrow trie\_ptr$ ;  $trie\_l[p] \leftarrow 0$ ;
  if  $first\_child$  then  $trie\_l[q] \leftarrow p$  else  $trie\_r[q] \leftarrow p$ ;
   $trie\_c[p] \leftarrow si(c)$ ;  $trie\_o[p] \leftarrow min\_quarterword$ ;
end

```

This code is used in sections 1138, 1852, and 1853.

```

1140. ⟨Compute the trie op code,  $v$ , and set  $l \leftarrow 0$  1140⟩ ≡
  if  $hc[1] = 0$  then  $hyf[0] \leftarrow 0$ ;
  if  $hc[k] = 0$  then  $hyf[k] \leftarrow 0$ ;
   $l \leftarrow k$ ;  $v \leftarrow min\_quarterword$ ;
  loop begin if  $hyf[l] \neq 0$  then  $v \leftarrow new\_trie\_op(k - l, hyf[l], v)$ ;
    if  $l > 0$  then  $decr(l)$  else goto done1;
  end;

```

done1:

This code is used in section 1138.

1141. Finally we put everything together: Here is how the trie gets to its final, efficient form. The following packing routine is rigged so that the root of the linked tree gets mapped into location 1 of *trie*, as required by the hyphenation algorithm. This happens because the first call of *first_fit* will “take” location 1.

⟨Declare procedures for preprocessing hyphenation patterns 1119⟩ +≡

```
procedure init_trie;
  var p: trie_pointer; { pointer for initialization }
      j, k, t: integer; { all-purpose registers for initialization }
      r, s: trie_pointer; { used to clean up the packed trie }
      h: two_halves; { template used to zero out trie’s holes }
  begin ⟨Get ready to compress the trie 1127⟩;
  if trie_root ≠ 0 then
    begin first_fit(trie_root); trie_pack(trie_root);
    end;
  if hyph_root ≠ 0 then ⟨Pack all stored hyph_codes 1854⟩;
  ⟨Move the data into trie 1133⟩;
  trie_not_ready ← false;
end;
```

1142. Breaking vertical lists into pages. The *vsplit* procedure, which implements TeX's `\vsplit` operation, is considerably simpler than *line_break* because it doesn't have to worry about hyphenation, and because its mission is to discover a single break instead of an optimum sequence of breakpoints. But before we get into the details of *vsplit*, we need to consider a few more basic things.

1143. A subroutine called *prune_page_top* takes a pointer to a vlist and returns a pointer to a modified vlist in which all glue, kern, and penalty nodes have been deleted before the first box or rule node. However, the first box or rule is actually preceded by a newly created glue node designed so that the topmost baseline will be at distance *split_top_skip* from the top, whenever this is possible without backspacing.

When the second argument *s* is *false* the deleted nodes are destroyed, otherwise they are collected in a list starting at *split_disc*.

In this routine and those that follow, we make use of the fact that a vertical list contains no character nodes, hence the *type* field exists for each node in the list.

```

define   discard_or_move = 60
function prune_page_top(p : pointer; s : boolean): pointer;
  label discard_or_move; { adjust top after page break }
  var prev_p : pointer; { lags one step behind p }
      q, r : pointer; { temporary variables for list manipulation }
  begin prev_p ← temp_head; link(temp_head) ← p;
  while p ≠ null do
    case type(p) of
      hlist_node, vlist_node, rule_node: ⟨ Insert glue for split_top_skip and set p ← null 1144 ⟩;
      whatsit_node, mark_node, ins_node: begin if (type(p) = whatsit_node) ∧ ((subtype(p) =
        pdf_snap_node) ∨ (subtype(p) = pdf_snap_comp_node)) then
        begin print("snap_node being discarded"); goto discard_or_move;
        end;
      prev_p ← p; p ← link(prev_p);
      end;
      glue_node, kern_node, penalty_node: begin discard_or_move: @{print("discard_or_move:");
        show_node_list(p); print_ln; @} q ← p; p ← link(q); link(q) ← null; link(prev_p) ← p;
        if s then
          begin if split_disc = null then split_disc ← q else link(r) ← q;
          r ← q;
          end
        else flush_node_list(q);
        end;
      othercases confusion("pruning")
    endcases;
  prev_p ← link(temp_head);
end;

```

```

1144. ⟨ Insert glue for split_top_skip and set p ← null 1144 ⟩ ≡
  begin q ← new_skip_param(split_top_skip_code); link(prev_p) ← q; link(q) ← p;
    { now temp_ptr = glue_ptr(q) }
  if width(temp_ptr) > height(p) then width(temp_ptr) ← width(temp_ptr) − height(p)
  else width(temp_ptr) ← 0;
  p ← null;
end

```

This code is used in section 1143.

1145. The next subroutine finds the best place to break a given vertical list so as to obtain a box of height h , with maximum depth d . A pointer to the beginning of the vertical list is given, and a pointer to the optimum breakpoint is returned. The list is effectively followed by a forced break, i.e., a penalty node with the *eject_penalty*; if the best break occurs at this artificial node, the value *null* is returned.

An array of six *scaled* distances is used to keep track of the height from the beginning of the list to the current place, just as in *line_break*. In fact, we use one of the same arrays, only changing its name to reflect its new significance.

```

define active_height  $\equiv$  active_width { new name for the six distance variables }
define cur_height  $\equiv$  active_height[1] { the natural height }
define set_height_zero(#)  $\equiv$  active_height[#]  $\leftarrow$  0 { initialize the height to zero }
define update_heights = 90 { go here to record glue in the active_height table }

function vert_break(p : pointer; h, d : scaled): pointer; { finds optimum page break }
  label done, not_found, update_heights;
  var prev_p: pointer; { if p is a glue node, type(prev_p) determines whether p is a legal breakpoint }
    q, r: pointer; { glue specifications }
    pi: integer; { penalty value }
    b: integer; { badness at a trial breakpoint }
    least_cost: integer; { the smallest badness plus penalties found so far }
    best_place: pointer; { the most recent break that leads to least_cost }
    prev_dp: scaled; { depth of previous box in the list }
    t: small_number; { type of the node following a kern }
  begin prev_p  $\leftarrow$  p; { an initial glue node is not a legal breakpoint }
  least_cost  $\leftarrow$  awful_bad; do_all_six(set_height_zero); prev_dp  $\leftarrow$  0;
  loop begin (If node p is a legal breakpoint, check if this break is the best known, and goto done if p is
    null or if the page-so-far is already too full to accept more stuff 1147);
    prev_p  $\leftarrow$  p; p  $\leftarrow$  link(prev_p);
  end;
done: vert_break  $\leftarrow$  best_place;
end;

```

1146. A global variable *best_height_plus_depth* will be set to the natural size of the box that corresponds to the optimum breakpoint found by *vert_break*. (This value is used by the insertion-splitting algorithm of the page builder.)

(Global variables 13) \equiv

best_height_plus_depth: *scaled*; { height of the best box, without stretching or shrinking }

1147. A subtle point to be noted here is that the maximum depth d might be negative, so *cur_height* and *prev_dp* might need to be corrected even after a glue or kern node.

```

⟨ If node  $p$  is a legal breakpoint, check if this break is the best known, and goto done if  $p$  is null or if the
page-so-far is already too full to accept more stuff 1147 ⟩ ≡
if  $p = \text{null}$  then  $pi \leftarrow \text{eject\_penalty}$ 
else ⟨ Use node  $p$  to update the current height and depth measurements; if this node is not a legal
breakpoint, goto not_found or update_heights, otherwise set  $pi$  to the associated penalty at the
break 1148 ⟩;
⟨ Check if node  $p$  is a new champion breakpoint; then goto done if  $p$  is a forced break or if the page-so-far
is already too full 1149 ⟩;
if  $(\text{type}(p) < \text{glue\_node}) \vee (\text{type}(p) > \text{kern\_node})$  then goto not_found;
update_heights: ⟨ Update the current height and depth measurements with respect to a glue or kern
node  $p$  1151 ⟩;
not_found: if  $\text{prev\_dp} > d$  then
    begin  $\text{cur\_height} \leftarrow \text{cur\_height} + \text{prev\_dp} - d$ ;  $\text{prev\_dp} \leftarrow d$ ;
end;

```

This code is used in section 1145.

1148. ⟨ Use node p to update the current height and depth measurements; if this node is not a legal breakpoint, **goto** *not_found* or *update_heights*, otherwise set pi to the associated penalty at the break 1148 ⟩ ≡

```

case  $\text{type}(p)$  of
    hlist_node, vlist_node, rule_node: begin
         $\text{cur\_height} \leftarrow \text{cur\_height} + \text{prev\_dp} + \text{height}(p)$ ;  $\text{prev\_dp} \leftarrow \text{depth}(p)$ ; goto not_found;
    end;
    whatsit_node: ⟨ Process whatsit  $p$  in vert_break loop, goto not_found 1609 ⟩;
    glue_node: if  $\text{precedes\_break}(\text{prev\_p})$  then  $pi \leftarrow 0$ 
        else goto update_heights;
    kern_node: begin if  $\text{link}(p) = \text{null}$  then  $t \leftarrow \text{penalty\_node}$ 
        else  $t \leftarrow \text{type}(\text{link}(p))$ ;
        if  $t = \text{glue\_node}$  then  $pi \leftarrow 0$  else goto update_heights;
    end;
    penalty_node:  $pi \leftarrow \text{penalty}(p)$ ;
    mark_node, ins_node: goto not_found;
othercases confusion("vertbreak")
endcases

```

This code is used in section 1147.

1149. **define** *deplorable* $\equiv 100000$ { more than *inf_bad*, but less than *awful_bad* }

⟨ Check if node *p* is a new champion breakpoint; then **goto** *done* if *p* is a forced break or if the page-so-far is already too full 1149 ⟩ \equiv

```

if pi < inf_penalty then
  begin ⟨ Compute the badness, b, using awful_bad if the box is too full 1150 ⟩;
  if b < awful_bad then
    if pi ≤ eject_penalty then b ← pi
    else if b < inf_bad then b ← b + pi
    else b ← deplorable;
  if b ≤ least_cost then
    begin best_place ← p; least_cost ← b; best_height_plus_depth ← cur_height + prev_dp;
    end;
  if (b = awful_bad) ∨ (pi ≤ eject_penalty) then goto done;
end

```

This code is used in section 1147.

1150. ⟨ Compute the badness, *b*, using *awful_bad* if the box is too full 1150 ⟩ \equiv

```

if cur_height < h then
  if (active_height[3] ≠ 0) ∨ (active_height[4] ≠ 0) ∨ (active_height[5] ≠ 0) then b ← 0
  else b ← badness(h − cur_height, active_height[2])
else if cur_height − h > active_height[6] then b ← awful_bad
  else b ← badness(cur_height − h, active_height[6])

```

This code is used in section 1149.

1151. Vertical lists that are subject to the *vert_break* procedure should not contain infinite shrinkability, since that would permit any amount of information to “fit” on one page.

⟨ Update the current height and depth measurements with respect to a glue or kern node *p* 1151 ⟩ \equiv

```

if type(p) = kern_node then q ← p
else begin q ← glue_ptr(p);
  active_height[2 + stretch_order(q)] ← active_height[2 + stretch_order(q)] + stretch(q);
  active_height[6] ← active_height[6] + shrink(q);
  if (shrink_order(q) ≠ normal) ∧ (shrink(q) ≠ 0) then
    begin
      print_err("Infinite_glue_shrinkage_found_in_box_being_split");
      help4("The_box_you_are_vsplitting_contains_some_infinately")
      ("shrinkable_glue, e.g., \vss_or \vskip_opt_minus_1fil.")
      ("Such_glue_doesn't_belong_there;but_you_can_safely_proceed,")
      ("since_the_offensive_shrinkability_has_been_made_finite.");
      error; r ← new_spec(q);
      shrink_order(r) ← normal; delete_glue_ref(q); glue_ptr(p) ← r; q ← r;
    end;
  end;
  cur_height ← cur_height + prev_dp + width(q); prev_dp ← 0

```

This code is used in section 1147.

1152. Now we are ready to consider *vsplit* itself. Most of its work is accomplished by the two subroutines that we have just considered.

Given the number of a vlist box n , and given a desired page height h , the *vsplit* function finds the best initial segment of the vlist and returns a box for a page of height h . The remainder of the vlist, if any, replaces the original box, after removing glue and penalties and adjusting for *split_top_skip*. Mark nodes in the split-off box are used to set the values of *split_first_mark* and *split_bot_mark*; we use the fact that *split_first_mark* = *null* if and only if *split_bot_mark* = *null*.

The original box becomes “void” if and only if it has been entirely extracted. The extracted box is “void” if and only if the original box was void (or if it was, erroneously, an hlist box).

⟨Declare the function called *do_marks* 1822⟩

```
function vsplit( $n$  : halfword;  $h$  : scaled): pointer; { extracts a page of height  $h$  from box  $n$  }
  label exit, done;
  var  $v$ : pointer; { the box to be split }
       $p$ : pointer; { runs through the vlist }
       $q$ : pointer; { points to where the break occurs }
  begin  $cur\_val \leftarrow n$ ; fetch_box( $v$ ); flush_node_list(split_disc); split_disc  $\leftarrow$  null;
  if sa_mark  $\neq$  null then
    if do_marks(vsplit_init, 0, sa_mark) then sa_mark  $\leftarrow$  null;
  if split_first_mark  $\neq$  null then
    begin delete_token_ref(split_first_mark); split_first_mark  $\leftarrow$  null; delete_token_ref(split_bot_mark);
          split_bot_mark  $\leftarrow$  null;
    end;
  ⟨Dispense with trivial cases of void or bad boxes 1153⟩;
   $q \leftarrow$  vert_break(list_ptr( $v$ ),  $h$ , split_max_depth);
  ⟨Look at all the marks in nodes before the break, and set the final link to null at the break 1154⟩;
   $q \leftarrow$  prune_page_top( $q$ , saving_vdiscards > 0);  $p \leftarrow$  list_ptr( $v$ ); free_node( $v$ , box_node_size);
  if  $q \neq$  null then  $q \leftarrow$  vpack( $q$ , natural);
  change_box( $q$ ); { the eq_level of the box stays the same }
  vsplit  $\leftarrow$  vpackage( $p$ ,  $h$ , exactly, split_max_depth);
exit: end;
```

1153. ⟨Dispense with trivial cases of void or bad boxes 1153⟩ \equiv

```
if  $v =$  null then
  begin vsplit  $\leftarrow$  null; return;
  end;
if type( $v$ )  $\neq$  vlist_node then
  begin print_err(""); print_esc("vsplit"); print("_needs_a_"); print_esc("vbox");
        help2("The_box_you_are_trying_to_split_is_an_hbox.")
        ("I_can't_split_such_a_box,_so_I'll_leave_it_alone."); error; vsplit  $\leftarrow$  null; return;
  end
```

This code is used in section 1152.

1154. It’s possible that the box begins with a penalty node that is the “best” break, so we must be careful to handle this special case correctly.

⟨ Look at all the marks in nodes before the break, and set the final link to *null* at the break 1154 ⟩ ≡

```

  p ← list_ptr(v);
  if p = q then list_ptr(v) ← null
  else loop begin if type(p) = mark_node then
    if mark_class(p) ≠ 0 then ⟨ Update the current marks for vsplit 1824 ⟩
    else if split_first_mark = null then
      begin split_first_mark ← mark_ptr(p); split_bot_mark ← split_first_mark;
      token_ref_count(split_first_mark) ← token_ref_count(split_first_mark) + 2;
      end
    else begin delete_token_ref(split_bot_mark); split_bot_mark ← mark_ptr(p);
      add_token_ref(split_bot_mark);
      end;
  if link(p) = q then
    begin link(p) ← null; goto done;
    end;
  p ← link(p);
  end;
done:
```

This code is used in section 1152.

1155. The page builder. When T_EX appends new material to its main vlist in vertical mode, it uses a method something like *vsplit* to decide where a page ends, except that the calculations are done “on line” as new items come in. The main complication in this process is that insertions must be put into their boxes and removed from the vlist, in a more-or-less optimum manner.

We shall use the term “current page” for that part of the main vlist that is being considered as a candidate for being broken off and sent to the user’s output routine. The current page starts at *link(page_head)*, and it ends at *page_tail*. We have *page_head = page_tail* if this list is empty.

Utter chaos would reign if the user kept changing page specifications while a page is being constructed, so the page builder keeps the pertinent specifications frozen as soon as the page receives its first box or insertion. The global variable *page_contents* is *empty* when the current page contains only mark nodes and content-less whatsit nodes; it is *inserts_only* if the page contains only insertion nodes in addition to marks and whatsits. Glue nodes, kern nodes, and penalty nodes are discarded until a box or rule node appears, at which time *page_contents* changes to *box_there*. As soon as *page_contents* becomes non-*empty*, the current *vsize* and *max_depth* are squirreled away into *page_goal* and *page_max_depth*; the latter values will be used until the page has been forwarded to the user’s output routine. The *\topskip* adjustment is made when *page_contents* changes to *box_there*.

Although *page_goal* starts out equal to *vsize*, it is decreased by the scaled natural height-plus-depth of the insertions considered so far, and by the *\skip* corrections for those insertions. Therefore it represents the size into which the non-inserted material should fit, assuming that all insertions in the current page have been made.

The global variables *best_page_break* and *least_page_cost* correspond respectively to the local variables *best_place* and *least_cost* in the *vert_break* routine that we have already studied; i.e., they record the location and value of the best place currently known for breaking the current page. The value of *page_goal* at the time of the best break is stored in *best_size*.

```
define inserts_only = 1 { page_contents when an insert node has been contributed, but no boxes }
define box_there = 2 { page_contents when a box or rule has been contributed }
```

⟨Global variables 13⟩ +≡

```
page_tail: pointer; { the final node on the current page }
page_contents: empty .. box_there; { what is on the current page so far? }
page_max_depth: scaled; { maximum box depth on page being built }
best_page_break: pointer; { break here to get the best page known so far }
least_page_cost: integer; { the score for this currently best page }
best_size: scaled; { its page_goal }
```


1156. The page builder has another data structure to keep track of insertions. This is a list of four-word nodes, starting and ending at *page_ins_head*. That is, the first element of the list is node $r_1 = \text{link}(\text{page_ins_head})$; node r_j is followed by $r_{j+1} = \text{link}(r_j)$; and if there are n items we have $r_{n+1} = \text{page_ins_head}$. The *subtype* field of each node in this list refers to an insertion number; for example, ‘\insert 250’ would correspond to a node whose *subtype* is $qi(250)$ (the same as the *subtype* field of the relevant *ins_node*). These *subtype* fields are in increasing order, and $\text{subtype}(\text{page_ins_head}) = qi(255)$, so *page_ins_head* serves as a convenient sentinel at the end of the list. A record is present for each insertion number that appears in the current page.

The *type* field in these nodes distinguishes two possibilities that might occur as we look ahead before deciding on the optimum page break. If $\text{type}(r) = \text{inserting}$, then $\text{height}(r)$ contains the total of the height-plus-depth dimensions of the box and all its inserts seen so far. If $\text{type}(r) = \text{split_up}$, then no more insertions will be made into this box, because at least one previous insertion was too big to fit on the current page; $\text{broken_ptr}(r)$ points to the node where that insertion will be split, if TeX decides to split it, $\text{broken_ins}(r)$ points to the insertion node that was tentatively split, and $\text{height}(r)$ includes also the natural height plus depth of the part that would be split off.

In both cases, $\text{last_ins_ptr}(r)$ points to the last *ins_node* encountered for box $qo(\text{subtype}(r))$ that would be at least partially inserted on the next page; and $\text{best_ins_ptr}(r)$ points to the last such *ins_node* that should actually be inserted, to get the page with minimum badness among all page breaks considered so far. We have $\text{best_ins_ptr}(r) = \text{null}$ if and only if no insertion for this box should be made to produce this optimum page.

The data structure definitions here use the fact that the *height* field appears in the fourth word of a box node.

```

define page_ins_node_size = 4 { number of words for a page insertion node }
define inserting = 0 { an insertion class that has not yet overflowed }
define split_up = 1 { an overflowed insertion class }
define broken_ptr(#)  $\equiv \text{link}(\# + 1)$  { an insertion for this class will break here if anywhere }
define broken_ins(#)  $\equiv \text{info}(\# + 1)$  { this insertion might break at broken_ptr }
define last_ins_ptr(#)  $\equiv \text{link}(\# + 2)$  { the most recent insertion for this subtype }
define best_ins_ptr(#)  $\equiv \text{info}(\# + 2)$  { the optimum most recent insertion }

⟨ Initialize the special list heads and constant nodes 964 ⟩ +≡
  subtype(page_ins_head)  $\leftarrow qi(255)$ ; type(page_ins_head)  $\leftarrow \text{split\_up}$ ; link(page_ins_head)  $\leftarrow \text{page\_ins\_head}$ ;

```

1157. An array *page-so-far* records the heights and depths of everything on the current page. This array contains six *scaled* numbers, like the similar arrays already considered in *line-break* and *vert-break*; and it also contains *page-goal* and *page-depth*, since these values are all accessible to the user via *set-page-dimen* commands. The value of *page-so-far*[1] is also called *page-total*. The stretch and shrink components of the *\skip* corrections for each insertion are included in *page-so-far*, but the natural space components of these corrections are not, since they have been subtracted from *page-goal*.

The variable *page-depth* records the depth of the current page; it has been adjusted so that it is at most *page-max-depth*. The variable *last-glue* points to the glue specification of the most recent node contributed from the contribution list, if this was a glue node; otherwise *last-glue* = *max_halfword*. (If the contribution list is nonempty, however, the value of *last-glue* is not necessarily accurate.) The variables *last-penalty*, *last-kern*, and *last-node-type* are similar. And finally, *insert_penalties* holds the sum of the penalties associated with all split and floating insertions.

```

define page_goal  $\equiv$  page_so_far[0] { desired height of information on page being built }
define page_total  $\equiv$  page_so_far[1] { height of the current page }
define page_shrink  $\equiv$  page_so_far[6] { shrinkability of the current page }
define page_depth  $\equiv$  page_so_far[7] { depth of the current page }

⟨Global variables 13⟩ +≡
page_so_far: array [0 .. 7] of scaled; { height and glue of the current page }
last_glue: pointer; { used to implement \lastskip }
last_penalty: integer; { used to implement \lastpenalty }
last_kern: scaled; { used to implement \lastkern }
last_node_type: integer; { used to implement \lastnodetype }
insert_penalties: integer; { sum of the penalties for insertions that were held over }

```

1158. ⟨Put each of TeX's primitives into the hash table 244⟩ +≡

```

primitive("pagegoal", set_page_dimen, 0); primitive("pagetotal", set_page_dimen, 1);
primitive("pagestretch", set_page_dimen, 2); primitive("pagefilstretch", set_page_dimen, 3);
primitive("pagefillstretch", set_page_dimen, 4); primitive("pagefilllstretch", set_page_dimen, 5);
primitive("pageshrink", set_page_dimen, 6); primitive("pagedepth", set_page_dimen, 7);

```

1159. ⟨Cases of *print_cmd_chr* for symbolic printing of primitives 245⟩ +≡

```

set_page_dimen: case chr_code of
  0: print_esc("pagegoal");
  1: print_esc("pagetotal");
  2: print_esc("pagestretch");
  3: print_esc("pagefilstretch");
  4: print_esc("pagefillstretch");
  5: print_esc("pagefilllstretch");
  6: print_esc("pageshrink");
othercases print_esc("pagedepth")
endcases;

```

```

1160. define print_plus_end(#)  $\equiv$  print(#); end
      define print_plus(#)  $\equiv$ 
        if page_so_far[#]  $\neq$  0 then
          begin print("_plus_"); print_scaled(page_so_far[#]); print_plus_end
procedure print_totals;
  begin print_scaled(page_total); print_plus(2)(""); print_plus(3)("fil"); print_plus(4)("fill");
  print_plus(5)("filll");
  if page_shrink  $\neq$  0 then
    begin print("_minus_"); print_scaled(page_shrink);
    end;
  end;

1161.  $\langle$  Show the status of the current page 1161  $\rangle \equiv$ 
  if page_head  $\neq$  page_tail then
    begin print_nl("###_current_page:");
    if output_active then print("_(held_over_for_next_output)");
    show_box(link(page_head));
    if page_contents > empty then
      begin print_nl("total_height_"); print_totals; print_nl("_goal_height_");
      print_scaled(page_goal); r  $\leftarrow$  link(page_ins_head);
      while r  $\neq$  page_ins_head do
        begin print_ln; print_esc("insert"); t  $\leftarrow$  qo(subtype(r)); print_int(t); print("_adds_");
        if count(t) = 1000 then t  $\leftarrow$  height(r)
        else t  $\leftarrow$  x_over_n(height(r), 1000) * count(t);
        print_scaled(t);
        if type(r) = split_up then
          begin q  $\leftarrow$  page_head; t  $\leftarrow$  0;
          repeat q  $\leftarrow$  link(q);
            if (type(q) = ins_node)  $\wedge$  (subtype(q) = subtype(r)) then incr(t);
          until q = broken_ins(r);
          print("_,_#"); print_int(t); print("_might_split");
          end;
          r  $\leftarrow$  link(r);
        end;
      end;
    end;
  end

```

This code is used in section 236.

1162. Here is a procedure that is called when the *page_contents* is changing from *empty* to *inserts_only* or *box_there*.

```

      define set_page_so_far_zero(#)  $\equiv$  page_so_far[#]  $\leftarrow$  0
procedure freeze_page_specs(s : small_number);
  begin page_contents  $\leftarrow$  s; page_goal  $\leftarrow$  vsize; page_max_depth  $\leftarrow$  max_depth; page_depth  $\leftarrow$  0;
  do_all_six(set_page_so_far_zero); least_page_cost  $\leftarrow$  awful_bad;
  stat if tracing_pages > 0 then
    begin begin_diagnostic; print_nl("%_goal_height="); print_scaled(page_goal);
    print("_,_max_depth="); print_scaled(page_max_depth); end_diagnostic(false);
    end; tats
  end;

```

1163. Pages are built by appending nodes to the current list in TeX's vertical mode, which is at the outermost level of the semantic nest. This vlist is split into two parts; the "current page" that we have been talking so much about already, and the "contribution list" that receives new nodes as they are created. The current page contains everything that the page builder has accounted for in its data structures, as described above, while the contribution list contains other things that have been generated by other parts of TeX but have not yet been seen by the page builder. The contribution list starts at *link(contrib_head)*, and it ends at the current node in TeX's vertical mode.

When TeX has appended new material in vertical mode, it calls the procedure *build_page*, which tries to catch up by moving nodes from the contribution list to the current page. This procedure will succeed in its goal of emptying the contribution list, unless a page break is discovered, i.e., unless the current page has grown to the point where the optimum next page break has been determined. In the latter case, the nodes after the optimum break will go back onto the contribution list, and control will effectively pass to the user's output routine.

We make *type(page_head) = glue_node*, so that an initial glue node on the current page will not be considered a valid breakpoint.

```
⟨ Initialize the special list heads and constant nodes 964 ⟩ +≡
  type(page_head) ← glue_node; subtype(page_head) ← normal;
```

1164. The global variable *output_active* is true during the time the user's output routine is driving TeX.

```
⟨ Global variables 13 ⟩ +≡
output_active: boolean; { are we in the midst of an output routine? }
```

```
1165. ⟨ Set initial values of key variables 21 ⟩ +≡
  output_active ← false; insert_penalties ← 0;
```

1166. The page builder is ready to start a fresh page if we initialize the following state variables. (However, the page insertion list is initialized elsewhere.)

```
⟨ Start a new current page 1166 ⟩ ≡
  page_contents ← empty; page_tail ← page_head; link(page_head) ← null;
  last_glue ← max_halfword; last_penalty ← 0; last_kern ← 0; last_node_type ← -1; page_depth ← 0;
  page_max_depth ← 0
```

This code is used in sections 233 and 1192.

1167. At certain times box 255 is supposed to be void (i.e., *null*), or an insertion box is supposed to be ready to accept a vertical list. If not, an error message is printed, and the following subroutine flushes the unwanted contents, reporting them to the user.

```
procedure box_error(n : eight_bits);
  begin error; begin_diagnostic; print_nl("The following box has been deleted:");
  show_box(box(n)); end_diagnostic(true); flush_node_list(box(n)); box(n) ← null;
end;
```

1168. The following procedure guarantees that a given box register does not contain an `\hbox`.

```
procedure ensure_vbox(n : eight_bits);
  var p: pointer; { the box register contents }
  begin p ← box(n);
  if p ≠ null then
    if type(p) = hlist_node then
      begin print_err("Insertions can only be added to a vbox");
      help3("Tut_tut: You're trying to \insert into a")
      (" \box register that now contains an \hbox.")
      ("Proceed, and I'll discard its present contents."); box_error(n);
      end;
    end;
end;
```

1169. TeX is not always in vertical mode at the time *build_page* is called; the current mode reflects what TeX should return to, after the contribution list has been emptied. A call on *build_page* should be immediately followed by ‘**goto** *big_switch*’, which is TeX’s central control point.

```
define contribute = 80 { go here to link a node into the current page }
⟨ Declare the procedure called fire_up 1187 ⟩
procedure build_page; { append contributions to the current page }
  label exit, done, done1, continue, contribute, update_heights;
  var p: pointer; { the node being appended }
      q, r: pointer; { nodes being examined }
      b, c: integer; { badness and cost of current page }
      pi: integer; { penalty to be added to the badness }
      n: min_quarterword .. 255; { insertion box number }
      delta, h, w: scaled; { sizes used for insertion calculations }
  begin if (link(contrib_head) = null) ∨ output_active then return;
  repeat continue: p ← link(contrib_head);
    ⟨ Update the values of last_glue, last_penalty, and last_kern 1171 ⟩;
    ⟨ Move node p to the current page; if it is time for a page break, put the nodes following the break
      back onto the contribution list, and return to the user’s output routine if there is one 1172 ⟩;
  until link(contrib_head) = null;
  ⟨ Make the contribution list empty by setting its tail to contrib_head 1170 ⟩;
exit: end;
```

1170. **define** *contrib_tail* ≡ *nest*[0].*tail_field* { tail of the contribution list }

⟨ Make the contribution list empty by setting its tail to *contrib_head* 1170 ⟩ ≡

```
if nest_ptr = 0 then tail ← contrib_head { vertical mode }
else contrib_tail ← contrib_head { other modes }
```

This code is used in section 1169.

1171. \langle Update the values of *last_glue*, *last_penalty*, and *last_kern* 1171 $\rangle \equiv$
if *last_glue* \neq *max_halfword* **then** *delete_glue_ref*(*last_glue*);
last_penalty \leftarrow 0; *last_kern* \leftarrow 0; *last_node_type* \leftarrow *type*(*p*) + 1;
if *type*(*p*) = *glue_node* **then**
 begin *last_glue* \leftarrow *glue_ptr*(*p*); *add_glue_ref*(*last_glue*);
 end
else begin *last_glue* \leftarrow *max_halfword*;
 if *type*(*p*) = *penalty_node* **then** *last_penalty* \leftarrow *penalty*(*p*)
 else if *type*(*p*) = *kern_node* **then** *last_kern* \leftarrow *width*(*p*);
 end

This code is used in section 1169.

1172. The code here is an example of a many-way switch into routines that merge together in different places. Some people call this unstructured programming, but the author doesn't see much wrong with it, as long as the various labels have a well-understood meaning.

\langle Move node *p* to the current page; if it is time for a page break, put the nodes following the break back onto the contribution list, and **return** to the user's output routine if there is one 1172 $\rangle \equiv$
 \langle If the current page is empty and node *p* is to be deleted, **goto** *done1*; otherwise use node *p* to update the state of the current page; if this node is an insertion, **goto** *contribute*; otherwise if this node is not a legal breakpoint, **goto** *contribute* or *update_heights*; otherwise set *pi* to the penalty associated with this breakpoint 1175 \rangle ;
 \langle Check if node *p* is a new champion breakpoint; then if it is time for a page break, prepare for output, and either fire up the user's output routine and **return** or ship out the page and **goto** *done* 1180 \rangle ;
if (*type*(*p*) < *glue_node*) \vee (*type*(*p*) > *kern_node*) **then goto** *contribute*;
update_heights: \langle Update the current page measurements with respect to the glue or kern specified by node *p* 1179 \rangle ;
contribute: \langle Make sure that *page_max_depth* is not exceeded 1178 \rangle ;
 \langle Link node *p* into the current page and **goto** *done* 1173 \rangle ;
done1: \langle Recycle node *p* 1174 \rangle ;
done:

This code is used in section 1169.

1173. \langle Link node *p* into the current page and **goto** *done* 1173 $\rangle \equiv$
link(*page_tail*) \leftarrow *p*; *page_tail* \leftarrow *p*; *link*(*contrib_head*) \leftarrow *link*(*p*); *link*(*p*) \leftarrow *null*; **goto** *done*

This code is used in section 1172.

1174. \langle Recycle node *p* 1174 $\rangle \equiv$
link(*contrib_head*) \leftarrow *link*(*p*); *link*(*p*) \leftarrow *null*;
if *saving_vdiscards* > 0 **then**
 begin if *page_disc* = *null* **then** *page_disc* \leftarrow *p* **else** *link*(*tail_page_disc*) \leftarrow *p*;
 tail_page_disc \leftarrow *p*;
 end
else flush_node_list(*p*)

This code is used in section 1172.

1175. The title of this section is already so long, it seems best to avoid making it more accurate but still longer, by mentioning the fact that a kern node at the end of the contribution list will not be contributed until we know its successor.

```

⟨If the current page is empty and node  $p$  is to be deleted, goto done1; otherwise use node  $p$  to update the
state of the current page; if this node is an insertion, goto contribute; otherwise if this node is not a
legal breakpoint, goto contribute or update_heights; otherwise set  $pi$  to the penalty associated with
this breakpoint 1175⟩ ≡
case type( $p$ ) of
  hlist_node, vlist_node, rule_node: if page_contents < box_there then
    ⟨Initialize the current page, insert the \topskip glue ahead of  $p$ , and goto continue 1176⟩
  else ⟨Prepare to move a box or rule node to the current page, then goto contribute 1177⟩;
  whatsit_node: if (page_contents < box_there) ∧ ((subtype( $p$ ) = pdf_snap_node) ∨ (subtype( $p$ ) =
    pdf_snap_comp_node)) then
    begin print("snap_node_being_discarded"); goto done1;
  end
  else ⟨Prepare to move whatsit  $p$  to the current page, then goto contribute 1608⟩;
  glue_node: if page_contents < box_there then goto done1
  else if precedes_break(page_tail) then  $pi \leftarrow 0$ 
  else goto update_heights;
  kern_node: if page_contents < box_there then goto done1
  else if link( $p$ ) = null then return
  else if type(link( $p$ )) = glue_node then  $pi \leftarrow 0$ 
  else goto update_heights;
  penalty_node: if page_contents < box_there then goto done1 else  $pi \leftarrow \text{penalty}(p)$ ;
  mark_node: goto contribute;
  ins_node: ⟨Append an insertion to the current page and goto contribute 1183⟩;
othercases confusion("page")
endcases

```

This code is used in section 1172.

```

1176. ⟨Initialize the current page, insert the \topskip glue ahead of  $p$ , and goto continue 1176⟩ ≡
begin if page_contents = empty then freeze_page_specs(box_there)
else page_contents ← box_there;
 $q \leftarrow \text{new\_skip\_param}(\text{top\_skip\_code})$ ; { now temp_ptr = glue_ptr( $q$ ) }
if width(temp_ptr) > height( $p$ ) then width(temp_ptr) ← width(temp_ptr) − height( $p$ )
else width(temp_ptr) ← 0;
 $\text{link}(q) \leftarrow p$ ;  $\text{link}(\text{contrib\_head}) \leftarrow q$ ; goto continue;
end

```

This code is used in section 1175.

```

1177. ⟨Prepare to move a box or rule node to the current page, then goto contribute 1177⟩ ≡
begin page_total ← page_total + page_depth + height( $p$ ); page_depth ← depth( $p$ ); goto contribute;
end

```

This code is used in section 1175.

```

1178. ⟨Make sure that page_max_depth is not exceeded 1178⟩ ≡
if page_depth > page_max_depth then
  begin page_total ← page_total + page_depth − page_max_depth;
  page_depth ← page_max_depth;
end;

```

This code is used in section 1172.

1179. \langle Update the current page measurements with respect to the glue or kern specified by node p 1179 $\rangle \equiv$

```

if  $type(p) = kern\_node$  then  $q \leftarrow p$ 
else begin  $q \leftarrow glue\_ptr(p)$ ;
   $page\_so\_far[2 + stretch\_order(q)] \leftarrow page\_so\_far[2 + stretch\_order(q)] + stretch(q)$ ;
   $page\_shrink \leftarrow page\_shrink + shrink(q)$ ;
  if  $(shrink\_order(q) \neq normal) \wedge (shrink(q) \neq 0)$  then
    begin
       $print\_err("Infinite\_glue\_shrinkage\_found\_on\_current\_page")$ ;
       $help4("The\_page\_about\_to\_be\_output\_contains\_some\_infinately")$ 
       $("shrinkable\_glue, \text{e.g., } \backslash vss\_or \backslash vskip\_opt\_minus\_1fil.")$ 
       $("Such\_glue\_doesn't\_belong\_there; \text{but you can safely proceed,}")$ 
       $("since\_the\_offensive\_shrinkability\_has\_been\_made\_finite.")$ ;  $error$ ;  $r \leftarrow new\_spec(q)$ ;
       $shrink\_order(r) \leftarrow normal$ ;  $delete\_glue\_ref(q)$ ;  $glue\_ptr(p) \leftarrow r$ ;  $q \leftarrow r$ ;
    end;
  end;
   $page\_total \leftarrow page\_total + page\_depth + width(q)$ ;  $page\_depth \leftarrow 0$ 

```

This code is used in section 1172.

1180. \langle Check if node p is a new champion breakpoint; then if it is time for a page break, prepare for output, and either fire up the user's output routine and **return** or ship out the page and **goto** done 1180 $\rangle \equiv$

```

if  $pi < inf\_penalty$  then
  begin  $\langle$  Compute the badness,  $b$ , of the current page, using  $awful\_bad$  if the box is too full 1182  $\rangle$ ;
  if  $b < awful\_bad$  then
    if  $pi \leq eject\_penalty$  then  $c \leftarrow pi$ 
    else if  $b < inf\_bad$  then  $c \leftarrow b + pi + insert\_penalties$ 
    else  $c \leftarrow deplorable$ 
  else  $c \leftarrow b$ ;
  if  $insert\_penalties \geq 10000$  then  $c \leftarrow awful\_bad$ ;
  stat if  $tracing\_pages > 0$  then  $\langle$  Display the page break cost 1181  $\rangle$ ;
  tats
  if  $c \leq least\_page\_cost$  then
    begin  $best\_page\_break \leftarrow p$ ;  $best\_size \leftarrow page\_goal$ ;  $least\_page\_cost \leftarrow c$ ;  $r \leftarrow link(page\_ins\_head)$ ;
    while  $r \neq page\_ins\_head$  do
      begin  $best\_ins\_ptr(r) \leftarrow last\_ins\_ptr(r)$ ;  $r \leftarrow link(r)$ ;
      end;
    end;
  if  $(c = awful\_bad) \vee (pi \leq eject\_penalty)$  then
    begin  $fire\_up(p)$ ; { output the current page at the best place }
    if  $output\_active$  then return; { user's output routine will act }
    goto  $done$ ; { the page has been shipped out by default output routine }
    end;
  end

```

This code is used in section 1172.

1181. \langle Display the page break cost [1181](#) $\rangle \equiv$
begin *begin_diagnostic*; *print_nl*("%"); *print*("␣t="); *print_totals*;
print("␣g="); *print_scaled*(*page_goal*);
print("␣b=");
if *b* = *awful_bad* **then** *print_char*("*") **else** *print_int*(*b*);
print("␣p="); *print_int*(*pi*); *print*("␣c=");
if *c* = *awful_bad* **then** *print_char*("*") **else** *print_int*(*c*);
if *c* ≤ *least_page_cost* **then** *print_char*("#");
end_diagnostic(*false*);
end

This code is used in section [1180](#).

1182. \langle Compute the badness, *b*, of the current page, using *awful_bad* if the box is too full [1182](#) $\rangle \equiv$
if *page_total* < *page_goal* **then**
 if (*page_so_far*[3] ≠ 0) ∨ (*page_so_far*[4] ≠ 0) ∨ (*page_so_far*[5] ≠ 0) **then** *b* ← 0
 else *b* ← *badness*(*page_goal* − *page_total*, *page_so_far*[2])
else if *page_total* − *page_goal* > *page_shrink* **then** *b* ← *awful_bad*
 else *b* ← *badness*(*page_total* − *page_goal*, *page_shrink*)

This code is used in section [1180](#).

1183. \langle Append an insertion to the current page and **goto** *contribute* [1183](#) $\rangle \equiv$
begin if *page_contents* = *empty* **then** *freeze_page_specs*(*inserts_only*);
n ← *subtype*(*p*); *r* ← *page_ins_head*;
while *n* ≥ *subtype*(*link*(*r*)) **do** *r* ← *link*(*r*);
n ← *qo*(*n*);
if *subtype*(*r*) ≠ *qi*(*n*) **then** \langle Create a page insertion node with *subtype*(*r*) = *qi*(*n*), and include the glue correction for box *n* in the current page state [1184](#) \rangle ;
if *type*(*r*) = *split_up* **then** *insert_penalties* ← *insert_penalties* + *float_cost*(*p*)
else begin *last_ins_ptr*(*r*) ← *p*; *delta* ← *page_goal* − *page_total* − *page_depth* + *page_shrink*;
 { this much room is left if we shrink the maximum }
 if *count*(*n*) = 1000 **then** *h* ← *height*(*p*)
 else *h* ← *x_over_n*(*height*(*p*), 1000) * *count*(*n*); { this much room is needed }
 if ((*h* ≤ 0) ∨ (*h* ≤ *delta*)) ∧ (*height*(*p*) + *height*(*r*) ≤ *dimen*(*n*)) **then**
 begin *page_goal* ← *page_goal* − *h*; *height*(*r*) ← *height*(*r*) + *height*(*p*);
 end
 else \langle Find the best way to split the insertion, and change *type*(*r*) to *split_up* [1185](#) \rangle ;
 end;
goto *contribute*;
end

This code is used in section [1175](#).

1184. We take note of the value of `\skip n` and the height plus depth of `\box n` only when the first `\insert n` node is encountered for a new page. A user who changes the contents of `\box n` after that first `\insert n` had better be either extremely careful or extremely lucky, or both.

```

⟨Create a page insertion node with  $subtype(r) = qi(n)$ , and include the glue correction for box  $n$  in the
current page state 1184⟩ ≡
begin q ← get_node(page_ins_node_size); link(q) ← link(r); link(r) ← q; r ← q; subtype(r) ← qi(n);
type(r) ← inserting; ensure_vbox(n);
if box(n) = null then height(r) ← 0
else height(r) ← height(box(n)) + depth(box(n));
best_ins_ptr(r) ← null;
q ← skip(n);
if count(n) = 1000 then h ← height(r)
else h ← x_over_n(height(r), 1000) * count(n);
page_goal ← page_goal - h - width(q);
page_so_far[2 + stretch_order(q)] ← page_so_far[2 + stretch_order(q)] + stretch(q);
page_shrink ← page_shrink + shrink(q);
if (shrink_order(q) ≠ normal) ∧ (shrink(q) ≠ 0) then
begin print_err("Infinite glue shrinkage inserted from "); print_esc("skip"); print_int(n);
help3("The correction glue for page breaking with insertions")
("must have finite shrinkability. But you may proceed,")
("since the offensive shrinkability has been made finite."); error;
end;
end

```

This code is used in section 1183.

1185. Here is the code that will split a long footnote between pages, in an emergency. The current situation deserves to be recapitulated: Node p is an insertion into box n ; the insertion will not fit, in its entirety, either because it would make the total contents of box n greater than `\dimen n`, or because it would make the incremental amount of growth h greater than the available space δ , or both. (This amount h has been weighted by the insertion scaling factor, i.e., by `\count n` over 1000.) Now we will choose the best way to break the vlist of the insertion, using the same criteria as in the `\vsplit` operation.

```

⟨Find the best way to split the insertion, and change  $type(r)$  to split-up 1185⟩ ≡
begin if count(n) ≤ 0 then w ← max_dimen
else begin w ← page_goal - page_total - page_depth;
if count(n) ≠ 1000 then w ← x_over_n(w, count(n)) * 1000;
end;
if w > dimen(n) - height(r) then w ← dimen(n) - height(r);
q ← vert_break(ins_ptr(p), w, depth(p)); height(r) ← height(r) + best_height_plus_depth;
stat if tracing_pages > 0 then ⟨Display the insertion split cost 1186⟩;
tats
if count(n) ≠ 1000 then best_height_plus_depth ← x_over_n(best_height_plus_depth, 1000) * count(n);
page_goal ← page_goal - best_height_plus_depth; type(r) ← split-up; broken_ptr(r) ← q;
broken_ins(r) ← p;
if q = null then insert_penalties ← insert_penalties + eject_penalty
else if type(q) = penalty_node then insert_penalties ← insert_penalties + penalty(q);
end

```

This code is used in section 1183.

1186. \langle Display the insertion split cost 1186 $\rangle \equiv$

```

begin begin_diagnostic; print_nl("%split"); print_int(n); print("to"); print_scaled(w);
print_char(" "); print_scaled(best_height_plus_depth);
print("p=");
if q = null then print_int(eject_penalty)
else if type(q) = penalty_node then print_int(penalty(q))
    else print_char("0");
end_diagnostic(false);
end

```

This code is used in section 1185.

1187. When the page builder has looked at as much material as could appear before the next page break, it makes its decision. The break that gave minimum badness will be used to put a completed “page” into box 255, with insertions appended to their other boxes.

We also set the values of *top_mark*, *first_mark*, and *bot_mark*. The program uses the fact that *bot_mark* \neq *null* implies *first_mark* \neq *null*; it also knows that *bot_mark* = *null* implies *top_mark* = *first_mark* = *null*.

The *fire_up* subroutine prepares to output the current page at the best place; then it fires up the user’s output routine, if there is one, or it simply ships out the page. There is one parameter, *c*, which represents the node that was being contributed to the page when the decision to force an output was made.

\langle Declare the procedure called *fire_up* 1187 $\rangle \equiv$

```

procedure fire_up(c : pointer);
    label exit;
    var p, q, r, s : pointer; { nodes being examined and/or changed }
    prev_p : pointer; { predecessor of p }
    n : min_quarterword .. 255; { insertion box number }
    wait : boolean; { should the present insertion be held over? }
    save_vbadness : integer; { saved value of vbadness }
    save_vfuzz : scaled; { saved value of vfuzz }
    save_split_top_skip : pointer; { saved value of split_top_skip }
    begin  $\langle$ Set the value of output_penalty 1188 $\rangle$ ;
    if sa_mark  $\neq$  null then
        if do_marks(fire_up_init, 0, sa_mark) then sa_mark  $\leftarrow$  null;
    if bot_mark  $\neq$  null then
        begin if top_mark  $\neq$  null then delete_token_ref(top_mark);
        top_mark  $\leftarrow$  bot_mark; add_token_ref(top_mark); delete_token_ref(first_mark); first_mark  $\leftarrow$  null;
        end;
     $\langle$ Put the optimal current page into box 255, update first_mark and bot_mark, append insertions to their
        boxes, and put the remaining nodes back on the contribution list 1189 $\rangle$ ;
    if sa_mark  $\neq$  null then
        if do_marks(fire_up_done, 0, sa_mark) then sa_mark  $\leftarrow$  null;
    if (top_mark  $\neq$  null)  $\wedge$  (first_mark = null) then
        begin first_mark  $\leftarrow$  top_mark; add_token_ref(top_mark);
        end;
    if output_routine  $\neq$  null then
        if dead_cycles  $\geq$  max_dead_cycles then
             $\langle$ Explain that too many dead cycles have occurred in a row 1199 $\rangle$ 
        else  $\langle$ Fire up the user’s output routine and return 1200 $\rangle$ ;
     $\langle$ Perform the default output routine 1198 $\rangle$ ;
    exit : end;

```

This code is used in section 1169.

1188. \langle Set the value of *output_penalty* 1188 $\rangle \equiv$
if *type*(*best_page_break*) = *penalty_node* **then**
 begin *geq_word_define*(*int_base* + *output_penalty_code*, *penalty*(*best_page_break*));
 penalty(*best_page_break*) \leftarrow *inf_penalty*;
 end
else *geq_word_define*(*int_base* + *output_penalty_code*, *inf_penalty*)

This code is used in section 1187.

1189. As the page is finally being prepared for output, pointer *p* runs through the vlist, with *prev_p* trailing behind; pointer *q* is the tail of a list of insertions that are being held over for a subsequent page.

\langle Put the optimal current page into box 255, update *first_mark* and *bot_mark*, append insertions to their boxes, and put the remaining nodes back on the contribution list 1189 $\rangle \equiv$
if *c* = *best_page_break* **then** *best_page_break* \leftarrow *null*; { *c* not yet linked in }
 \langle Ensure that box 255 is empty before output 1190 \rangle ;
insert_penalties \leftarrow 0; { this will count the number of insertions held over }
save_split_top_skip \leftarrow *split_top_skip*;
if *holding_inserts* \leq 0 **then** \langle Prepare all the boxes involved in insertions to act as queues 1193 \rangle ;
q \leftarrow *hold_head*; *link*(*q*) \leftarrow *null*; *prev_p* \leftarrow *page_head*; *p* \leftarrow *link*(*prev_p*);
while *p* \neq *best_page_break* **do**
 begin if *type*(*p*) = *ins_node* **then**
 begin if *holding_inserts* \leq 0 **then** \langle Either insert the material specified by node *p* into the appropriate box, or hold it for the next page; also delete node *p* from the current page 1195 \rangle ;
 end
 else if *type*(*p*) = *mark_node* **then**
 if *mark_class*(*p*) \neq 0 **then** \langle Update the current marks for *fire_up* 1827 \rangle
 else \langle Update the values of *first_mark* and *bot_mark* 1191 \rangle ;
 prev_p \leftarrow *p*; *p* \leftarrow *link*(*prev_p*);
 end;
split_top_skip \leftarrow *save_split_top_skip*; \langle Break the current page at node *p*, put it in box 255, and put the remaining nodes on the contribution list 1192 \rangle ;
 \langle Delete the page-insertion nodes 1194 \rangle

This code is used in section 1187.

1190. \langle Ensure that box 255 is empty before output 1190 $\rangle \equiv$
if *box*(255) \neq *null* **then**
 begin *print_err*(""); *print_esc*("box"); *print*("255_is_not_void");
 help2("You shouldn't use \box255 except in \output routines.")
 ("Proceed, and I'll discard its present contents."); *box_error*(255);
 end

This code is used in section 1189.

1191. \langle Update the values of *first_mark* and *bot_mark* 1191 $\rangle \equiv$
begin if *first_mark* = *null* **then**
 begin *first_mark* \leftarrow *mark_ptr*(*p*); *add_token_ref*(*first_mark*);
 end;
if *bot_mark* \neq *null* **then** *delete_token_ref*(*bot_mark*);
 bot_mark \leftarrow *mark_ptr*(*p*); *add_token_ref*(*bot_mark*);
end

This code is used in section 1189.

1192. When the following code is executed, the current page runs from node *link(page_head)* to node *prev_p*, and the nodes from *p* to *page_tail* are to be placed back at the front of the contribution list. Furthermore the heldover insertions appear in a list from *link(hold_head)* to *q*; we will put them into the current page list for safekeeping while the user's output routine is active. We might have *q = hold_head*; and *p = null* if and only if *prev_p = page_tail*. Error messages are suppressed within *vpackage*, since the box might appear to be overfull or underfull simply because the stretch and shrink from the `\skip` registers for inserts are not actually present in the box.

```

⟨Break the current page at node p, put it in box 255, and put the remaining nodes on the contribution
  list 1192⟩ ≡
if p ≠ null then
  begin if link(contrib_head) = null then
    if nest_ptr = 0 then tail ← page_tail
    else contrib_tail ← page_tail;
    link(page_tail) ← link(contrib_head); link(contrib_head) ← p; link(prev_p) ← null;
  end;
save_vbadness ← vbadness; vbadness ← inf_bad; save_vfuzz ← vfuzz; vfuzz ← max_dimen;
  {inhibit error messages}
box(255) ← vpackage(link(page_head), best_size, exactly, page_max_depth); vbadness ← save_vbadness;
vfuzz ← save_vfuzz;
if last_glue ≠ max_halfword then delete_glue_ref(last_glue);
⟨Start a new current page 1166⟩; {this sets last_glue ← max_halfword}
if q ≠ hold_head then
  begin link(page_head) ← link(hold_head); page_tail ← q;
end

```

This code is used in section 1189.

1193. If many insertions are supposed to go into the same box, we want to know the position of the last node in that box, so that we don't need to waste time when linking further information into it. The *last_ins_ptr* fields of the page insertion nodes are therefore used for this purpose during the packaging phase.

```

⟨Prepare all the boxes involved in insertions to act as queues 1193⟩ ≡
begin r ← link(page_ins_head);
while r ≠ page_ins_head do
  begin if best_ins_ptr(r) ≠ null then
    begin n ← qo(subtype(r)); ensure_vbox(n);
    if box(n) = null then box(n) ← new_null_box;
    p ← box(n) + list_offset;
    while link(p) ≠ null do p ← link(p);
    last_ins_ptr(r) ← p;
  end;
  r ← link(r);
end;
end

```

This code is used in section 1189.

```

1194. ⟨Delete the page-insertion nodes 1194⟩ ≡
  r ← link(page_ins_head);
  while r ≠ page_ins_head do
    begin q ← link(r); free_node(r, page_ins_node_size); r ← q;
    end;
  link(page_ins_head) ← page_ins_head

```

This code is used in section 1189.

1195. We will set $best_ins_ptr \leftarrow null$ and package the box corresponding to insertion node r , just after making the final insertion into that box. If this final insertion is ‘*split_up*’, the remainder after splitting and pruning (if any) will be carried over to the next page.

```

⟨ Either insert the material specified by node  $p$  into the appropriate box, or hold it for the next page; also
  delete node  $p$  from the current page 1195 ⟩ ≡
begin  $r \leftarrow link(page\_ins\_head)$ ;
while  $subtype(r) \neq subtype(p)$  do  $r \leftarrow link(r)$ ;
if  $best\_ins\_ptr(r) = null$  then  $wait \leftarrow true$ 
else begin  $wait \leftarrow false$ ;  $s \leftarrow last\_ins\_ptr(r)$ ;  $link(s) \leftarrow ins\_ptr(p)$ ;
  if  $best\_ins\_ptr(r) = p$  then ⟨ Wrap up the box specified by node  $r$ , splitting node  $p$  if called for; set
     $wait \leftarrow true$  if node  $p$  holds a remainder after splitting 1196 ⟩
  else begin while  $link(s) \neq null$  do  $s \leftarrow link(s)$ ;
     $last\_ins\_ptr(r) \leftarrow s$ ;
  end;
end;
⟨ Either append the insertion node  $p$  after node  $q$ , and remove it from the current page, or delete
  node( $p$ ) 1197 ⟩;
end

```

This code is used in section 1189.

1196. ⟨ Wrap up the box specified by node r , splitting node p if called for; set $wait \leftarrow true$ if node p holds a remainder after splitting 1196 ⟩ ≡

```

begin if  $type(r) = split\_up$  then
  if  $(broken\_ins(r) = p) \wedge (broken\_ptr(r) \neq null)$  then
    begin while  $link(s) \neq broken\_ptr(r)$  do  $s \leftarrow link(s)$ ;
       $link(s) \leftarrow null$ ;  $split\_top\_skip \leftarrow split\_top\_ptr(p)$ ;  $ins\_ptr(p) \leftarrow prune\_page\_top(broken\_ptr(r), false)$ ;
    if  $ins\_ptr(p) \neq null$  then
      begin  $temp\_ptr \leftarrow vpack(ins\_ptr(p), natural)$ ;  $height(p) \leftarrow height(temp\_ptr) + depth(temp\_ptr)$ ;
         $free\_node(temp\_ptr, box\_node\_size)$ ;  $wait \leftarrow true$ ;
      end;
    end;
   $best\_ins\_ptr(r) \leftarrow null$ ;  $n \leftarrow go(subtype(r))$ ;  $temp\_ptr \leftarrow list\_ptr(box(n))$ ;
   $free\_node(box(n), box\_node\_size)$ ;  $box(n) \leftarrow vpack(temp\_ptr, natural)$ ;
end

```

This code is used in section 1195.

1197. ⟨ Either append the insertion node p after node q , and remove it from the current page, or delete node(p) 1197 ⟩ ≡

```

 $link(prev\_p) \leftarrow link(p)$ ;  $link(p) \leftarrow null$ ;
if  $wait$  then
  begin  $link(q) \leftarrow p$ ;  $q \leftarrow p$ ;  $incr(insert\_penalties)$ ;
  end
else begin  $delete\_glue\_ref(split\_top\_ptr(p))$ ;  $free\_node(p, ins\_node\_size)$ ;
  end;
 $p \leftarrow prev\_p$ 

```

This code is used in section 1195.

1198. The list of heldover insertions, running from *link(page_head)* to *page_tail*, must be moved to the contribution list when the user has specified no output routine.

```

⟨Perform the default output routine 1198⟩ ≡
  begin if link(page_head) ≠ null then
    begin if link(contrib_head) = null then
      if nest_ptr = 0 then tail ← page_tail else contrib_tail ← page_tail
    else link(page_tail) ← link(contrib_head);
      link(contrib_head) ← link(page_head); link(page_head) ← null; page_tail ← page_head;
    end;
    flush_node_list(page_disc); page_disc ← null; ship_out(box(255)); box(255) ← null;
  end

```

This code is used in section 1187.

```

1199. ⟨Explain that too many dead cycles have occurred in a row 1199⟩ ≡
  begin print_err("Output loop---"); print_int(dead_cycles); print(" consecutive dead cycles");
  help3("I've concluded that your \output is awry; it never does a")
  ("\shipout, so I'm shipping \box255 out myself. Next time")
  ("increase \maxdeadcycles if you want me to be more patient!"); error;
  end

```

This code is used in section 1187.

```

1200. ⟨Fire up the user's output routine and return 1200⟩ ≡
  begin output_active ← true; incr(dead_cycles); push_nest; mode ← -vmode;
  prev_depth ← pdf_ignored_dimen; mode_line ← -line; begin_token_list(output_routine, output_text);
  new_save_level(output_group); normal_paragraph; scan_left_brace; return;
  end

```

This code is used in section 1187.

1201. When the user's output routine finishes, it has constructed a vlist in internal vertical mode, and TeX will do the following:

```

⟨Resume the page builder after an output routine has come to an end 1201⟩ ≡
  begin if (loc ≠ null) ∨ ((token_type ≠ output_text) ∧ (token_type ≠ backed_up)) then
    ⟨Recover from an unbalanced output routine 1202⟩;
    end_token_list; {conserve stack space in case more outputs are triggered}
    end_graf; unsave; output_active ← false; insert_penalties ← 0;
    ⟨Ensure that box 255 is empty after output 1203⟩;
    if tail ≠ head then {current list goes after heldover insertions}
      begin link(page_tail) ← link(head); page_tail ← tail;
      end;
    if link(page_head) ≠ null then {and both go before heldover contributions}
      begin if link(contrib_head) = null then contrib_tail ← page_tail;
        link(page_tail) ← link(contrib_head); link(contrib_head) ← link(page_head); link(page_head) ← null;
        page_tail ← page_head;
      end;
      flush_node_list(page_disc); page_disc ← null; pop_nest; build_page;
    end
  end

```

This code is used in section 1276.

1202. \langle Recover from an unbalanced output routine 1202 $\rangle \equiv$

```

begin print_err("Unbalanced_output_routine");
help2("Your_sneaky_output_routine_has_problematic_{s_and/or}s.")
("I_can't_handle_that_very_well;_good_luck."); error;
repeat get_token;
until loc = null;
end { loops forever if reading from a file, since null = min_halfword  $\leq 0$  }

```

This code is used in section 1201.

1203. \langle Ensure that box 255 is empty after output 1203 $\rangle \equiv$

```

if box(255)  $\neq$  null then
  begin print_err("Output_routine_didn't_use_all_of"); print_esc("box"); print_int(255);
  help3("Your_output_commands_should_empty_box255,")
  ("e.g.,_by_saying_`shipout_box255'")
  ("Proceed;_I'll_discard_its_present_contents."); box_error(255);
  end

```

This code is used in section 1201.

1204. The chief executive. We come now to the *main_control* routine, which contains the master switch that causes all the various pieces of TeX to do their things, in the right order.

In a sense, this is the grand climax of the program: It applies all the tools that we have worked so hard to construct. In another sense, this is the messiest part of the program: It necessarily refers to other pieces of code all over the place, so that a person can't fully understand what is going on without paging back and forth to be reminded of conventions that are defined elsewhere. We are now at the hub of the web, the central nervous system that touches most of the other parts and ties them together.

The structure of *main_control* itself is quite simple. There's a label called *big_switch*, at which point the next token of input is fetched using *get_x_token*. Then the program branches at high speed into one of about 100 possible directions, based on the value of the current mode and the newly fetched command code; the sum $abs(mode) + cur_cmd$ indicates what to do next. For example, the case '*vmode* + *letter*' arises when a letter occurs in vertical mode (or internal vertical mode); this case leads to instructions that initialize a new paragraph and enter horizontal mode.

The big **case** statement that contains this multiway switch has been labeled *reswitch*, so that the program can **goto** *reswitch* when the next token has already been fetched. Most of the cases are quite short; they call an "action procedure" that does the work for that case, and then they either **goto** *reswitch* or they "fall through" to the end of the **case** statement, which returns control back to *big_switch*. Thus, *main_control* is not an extremely large procedure, in spite of the multiplicity of things it must do; it is small enough to be handled by Pascal compilers that put severe restrictions on procedure size.

One case is singled out for special treatment, because it accounts for most of TeX's activities in typical applications. The process of reading simple text and converting it into *char_node* records, while looking for ligatures and kerns, is part of TeX's "inner loop"; the whole program runs efficiently when its inner loop is fast, so this part has been written with particular care.

1205. We shall concentrate first on the inner loop of *main_control*, deferring consideration of the other cases until later.

```

define big_switch = 60 { go here to branch on the next token of input }
define main_loop = 70 { go here to typeset a string of consecutive characters }
define main_loop_wrapup = 80 { go here to finish a character or ligature }
define main_loop_move = 90 { go here to advance the ligature cursor }
define main_loop_move_lig = 95 { same, when advancing past a generated ligature }
define main_loop_lookahead = 100 { go here to bring in another character, if any }
define main_lig_loop = 110 { go here to check for ligatures or kerning }
define append_normal_space = 120 { go here to append a normal space between words }

⟨ Declare action procedures for use by main_control 1219 ⟩
⟨ Declare the procedure called handle_right_brace 1244 ⟩
procedure main_control; { governs TeX's activities }
  label big_switch, reswitch, main_loop, main_loop_wrapup, main_loop_move, main_loop_move + 1,
    main_loop_move + 2, main_loop_move_lig, main_loop_lookahead, main_loop_lookahead + 1,
    main_lig_loop, main_lig_loop + 1, main_lig_loop + 2, append_normal_space, exit;
  var t: integer; { general-purpose temporary variable }
    tmp_k1, tmp_k2: pointer; { for testing whether an auto kern should be inserted }
  begin if every_job ≠ null then begin_token_list(every_job, every_job_text);
big_switch: get_x_token;
reswitch: ⟨ Give diagnostic information, if requested 1206 ⟩;
  case abs(mode) + cur_cmd of
    hmode + letter, hmode + other_char, hmode + char_given: goto main_loop;
    hmode + char_num: begin scan_char_num; cur_chr ← cur_val; goto main_loop; end;
    hmode + no_boundary: begin get_x_token;
      if (cur_cmd = letter) ∨ (cur_cmd = other_char) ∨ (cur_cmd = char_given) ∨ (cur_cmd = char_num)
        then cancel_boundary ← true;
      goto reswitch;
    end;
    hmode + spacer: if (space_factor = 1000) ∨ (pdf_adjust_interword_glue > 0) then
      goto append_normal_space
    else app_space;
    hmode + ex_space, mmode + ex_space: goto append_normal_space;
  ⟨ Cases of main_control that are not part of the inner loop 1221 ⟩
end; { of the big case statement }
goto big_switch;
main_loop: ⟨ Append character cur_chr and the following characters (if any) to the current hlist in the
  current font; goto reswitch when a non-character has been fetched 1209 ⟩;
append_normal_space: ⟨ Append a normal inter-word space to the current list, then goto big_switch 1217 ⟩;
exit: end;

```

1206. When a new token has just been fetched at *big_switch*, we have an ideal place to monitor TeX's activity.

```

⟨ Give diagnostic information, if requested 1206 ⟩ ≡
  if interrupt ≠ 0 then
    if OK_to_interrupt then
      begin back_input; check_interrupt; goto big_switch;
    end;
  debug if panicking then check_mem(false); gubed
  if tracing_commands > 0 then show_cur_cmd_chr

```

This code is used in section 1205.

1207. The following part of the program was first written in a structured manner, according to the philosophy that “premature optimization is the root of all evil.” Then it was rearranged into pieces of spaghetti so that the most common actions could proceed with little or no redundancy.

The original unoptimized form of this algorithm resembles the *reconstitute* procedure, which was described earlier in connection with hyphenation. Again we have an implied “cursor” between characters *cur_l* and *cur_r*. The main difference is that the *lig_stack* can now contain a charnode as well as pseudo-ligatures; that stack is now usually nonempty, because the next character of input (if any) has been appended to it. In *main_control* we have

$$cur_r = \begin{cases} character(lig_stack), & \text{if } lig_stack > null; \\ font_bchar[cur_font], & \text{otherwise;} \end{cases}$$

except when $character(lig_stack) = font_false_bchar[cur_font]$. Several additional global variables are needed.

⟨Global variables 13⟩ +≡

main_f: *internal_font_number*; { the current font }

main_i: *four_quarters*; { character information bytes for *cur_l* }

main_j: *four_quarters*; { ligature/kern command }

main_k: *font_index*; { index into *font_info* }

main_p: *pointer*; { temporary register for list manipulation }

main_s: *integer*; { space factor value }

bchar: *halfword*; { boundary character of current font, or *non_char* }

false_bchar: *halfword*; { nonexistent character matching *bchar*, or *non_char* }

cancel_boundary: *boolean*; { should the left boundary be ignored? }

ins_disc: *boolean*; { should we insert a discretionary node? }

1208. The boolean variables of the main loop are normally false, and always reset to false before the loop is left. That saves us the extra work of initializing each time.

⟨Set initial values of key variables 21⟩ +≡

ligature_present ← *false*; *cancel_boundary* ← *false*; *lft_hit* ← *false*; *rt_hit* ← *false*; *ins_disc* ← *false*;

1209. We leave the *space_factor* unchanged if *sf_code*(*cur_chr*) = 0; otherwise we set it equal to *sf_code*(*cur_chr*), except that it should never change from a value less than 1000 to a value exceeding 1000. The most common case is *sf_code*(*cur_chr*) = 1000, so we want that case to be fast.

The overall structure of the main loop is presented here. Some program labels are inside the individual sections.

```

define adjust_space_factor ≡
    main_s ← sf_code(cur_chr);
    if main_s = 1000 then space_factor ← 1000
    else if main_s < 1000 then
        begin if main_s > 0 then space_factor ← main_s;
        end
        else if space_factor < 1000 then space_factor ← 1000
        else space_factor ← main_s
    end
⟨Append character cur_chr and the following characters (if any) to the current hlist in the current font;
goto reswitch when a non-character has been fetched 1209⟩ ≡
    adjust_space_factor;
    save_tail ← null; main_f ← cur_font; bchar ← font_bchar[main_f];
    false_bchar ← font_false_bchar[main_f];
    if mode > 0 then
        if language ≠ clang then fix_language;
        fast_get_avail(lig_stack); font(lig_stack) ← main_f; cur_l ← qi(cur_chr); character(lig_stack) ← cur_l;
        cur_q ← tail; tmp.k1 ← get_auto_kern(main_f, non_char, cur_l);
        ⟨If tmp.k1 is not null then append that kern 1215⟩;
    if cancel_boundary then
        begin cancel_boundary ← false; main_k ← non_address;
        end
    else main_k ← bchar_label[main_f];
    if main_k = non_address then goto main_loop_move + 2; { no left boundary processing }
    cur_r ← cur_l; cur_l ← non_char; goto main_lig_loop + 1; { begin with cursor after left boundary }
main_loop_wrapup: ⟨Make a ligature node, if ligature_present; insert a null discretionary, if
    appropriate 1210⟩;
main_loop_move: ⟨If the cursor is immediately followed by the right boundary, goto reswitch; if it's
    followed by an invalid character, goto big_switch; otherwise move the cursor one step to the right
    and goto main_lig_loop 1211⟩;
main_loop_lookahead: ⟨Look ahead for another character, or leave lig_stack empty if there's none there 1213⟩;
main_lig_loop: ⟨If there's a ligature/kern command relevant to cur_l and cur_r, adjust the text
    appropriately; exit to main_loop_wrapup 1214⟩;
main_loop_move_lig: ⟨Move the cursor past a pseudo-ligature, then goto main_loop_lookahead or
    main_lig_loop 1212⟩

```

This code is used in section 1205.

1210. If *link*(*cur_q*) is nonnull when *wrapup* is invoked, *cur_q* points to the list of characters that were consumed while building the ligature character *cur_l*.

A discretionary break is not inserted for an explicit hyphen when we are in restricted horizontal mode. In particular, this avoids putting discretionary nodes inside of other discretions.

```

define pack_lig(#)  $\equiv$  { the parameter is either rt_hit or false }
begin main_p  $\leftarrow$  new_ligature(main_f, cur_l, link(cur_q));
if lft_hit then
  begin subtype(main_p)  $\leftarrow$  2; lft_hit  $\leftarrow$  false;
end;
if # then
  if lig_stack = null then
    begin incr(subtype(main_p)); rt_hit  $\leftarrow$  false;
    end;
if pdf_prepend_kern > 0 then tmp_k2  $\leftarrow$  get_auto_kern(main_f, non_char, cur_l)
else tmp_k2  $\leftarrow$  null;
if tmp_k2 = null then
  begin link(cur_q)  $\leftarrow$  main_p; tail  $\leftarrow$  main_p; ligature_present  $\leftarrow$  false;
  end
else begin link(cur_q)  $\leftarrow$  tmp_k2; link(tmp_k2)  $\leftarrow$  main_p; tail  $\leftarrow$  main_p;
  ligature_present  $\leftarrow$  false;
  end
end
define wrapup(#)  $\equiv$ 
  if cur_l < non_char then
    begin if link(cur_q) > null then
      if character(tail) = qi(hyphen_char[main_f]) then ins_disc  $\leftarrow$  true;
      if ligature_present then pack_lig(#);
      if ins_disc then
        begin ins_disc  $\leftarrow$  false;
        if mode > 0 then tail_append(new_disc);
        end;
      end
    end
  end

```

\langle Make a ligature node, if *ligature_present*; insert a null discretionary, if appropriate 1210 $\rangle \equiv$
wrapup(*rt_hit*)

This code is used in section 1209.

1211. \langle If the cursor is immediately followed by the right boundary, **goto** *reswitch*; if it's followed by an invalid character, **goto** *big_switch*; otherwise move the cursor one step to the right and **goto** *main_lig_loop* 1211 $\rangle \equiv$

```

if lig_stack = null then goto reswitch;
cur_q  $\leftarrow$  tail; cur_l  $\leftarrow$  character(lig_stack);
main_loop_move + 1: if  $\neg$ is_char_node(lig_stack) then goto main_loop_move_lig;
main_loop_move + 2: if (cur_chr < font_bc[main_f])  $\vee$  (cur_chr > font_ec[main_f]) then
  begin char_warning(main_f, cur_chr); free_avail(lig_stack); goto big_switch;
  end;
main_i  $\leftarrow$  char_info(main_f)(cur_l);
if  $\neg$ char_exists(main_i) then
  begin char_warning(main_f, cur_chr); free_avail(lig_stack); goto big_switch;
  end;
link(tail)  $\leftarrow$  lig_stack; tail  $\leftarrow$  lig_stack { main_loop_lookahead is next }

```

This code is used in section 1209.

1212. Here we are at *main_loop_move_lig*. When we begin this code we have *cur_q* = *tail* and *cur_l* = *character(lig_stack)*.

```

⟨Move the cursor past a pseudo-ligature, then goto main_loop_lookahead or main_lig_loop 1212⟩ ≡
  main_p ← lig_ptr(lig_stack);
  if main_p > null then tail_append(main_p); { append a single character }
  temp_ptr ← lig_stack; lig_stack ← link(temp_ptr); free_node(temp_ptr, small_node_size);
  main_i ← char_info(main_f)(cur_l); ligature_present ← true;
  if lig_stack = null then
    if main_p > null then goto main_loop_lookahead
    else cur_r ← bchar
  else cur_r ← character(lig_stack);
  goto main_lig_loop

```

This code is used in section 1209.

1213. The result of `\char` can participate in a ligature or kern, so we must look ahead for it.

```

⟨Look ahead for another character, or leave lig_stack empty if there's none there 1213⟩ ≡
  get_next; { set only cur_cmd and cur_chr, for speed }
  if cur_cmd = letter then goto main_loop_lookahead + 1;
  if cur_cmd = other_char then goto main_loop_lookahead + 1;
  if cur_cmd = char_given then goto main_loop_lookahead + 1;
  x_token; { now expand and set cur_cmd, cur_chr, cur_tok }
  if cur_cmd = letter then goto main_loop_lookahead + 1;
  if cur_cmd = other_char then goto main_loop_lookahead + 1;
  if cur_cmd = char_given then goto main_loop_lookahead + 1;
  if cur_cmd = char_num then
    begin scan_char_num; cur_chr ← cur_val; goto main_loop_lookahead + 1;
    end;
  if cur_cmd = no_boundary then bchar ← non_char;
  cur_r ← bchar; lig_stack ← null; goto main_lig_loop;
main_loop_lookahead + 1: adjust_space_factor; fast_get_avail(lig_stack); font(lig_stack) ← main_f;
  cur_r ← qi(cur_chr); character(lig_stack) ← cur_r;
  if cur_r = false_bchar then cur_r ← non_char { this prevents spurious ligatures }

```

This code is used in section 1209.

1214. Even though comparatively few characters have a lig/kern program, several of the instructions here count as part of TeX's inner loop, since a potentially long sequential search must be performed. For example, tests with Computer Modern Roman showed that about 40 per cent of all characters actually encountered in practice had a lig/kern program, and that about four lig/kern commands were investigated for every such character.

At the beginning of this code we have $main_i = char_info(main_f)(cur_l)$.

⟨If there's a ligature/kern command relevant to cur_l and cur_r , adjust the text appropriately; exit to

```

    main_loop_wrapup 1214⟩ ≡
    tmp_k1 ← get_auto_kern(main_f, cur_l, cur_r); ⟨If tmp_k1 is not null then append that kern 1215⟩;
    if char_tag(main_i) ≠ lig_tag then goto main_loop_wrapup;
    if cur_r = non_char then goto main_loop_wrapup;
    main_k ← lig_kern_start(main_f)(main_i); main_j ← font_info[main_k].qqqq;
    if skip_byte(main_j) ≤ stop_flag then goto main_lig_loop + 2;
    main_k ← lig_kern_restart(main_f)(main_j);
main_lig_loop + 1: main_j ← font_info[main_k].qqqq;
main_lig_loop + 2: if next_char(main_j) = cur_r then
    if skip_byte(main_j) ≤ stop_flag then ⟨Do ligature or kern command, returning to main_lig_loop or
        main_loop_wrapup or main_loop_move 1216⟩;
    if skip_byte(main_j) = qi(0) then incr(main_k)
    else begin if skip_byte(main_j) ≥ stop_flag then goto main_loop_wrapup;
        main_k ← main_k + qo(skip_byte(main_j)) + 1;
    end;
    goto main_lig_loop + 1

```

This code is used in section 1209.

1215. ⟨If tmp_k1 is not null then append that kern 1215⟩ ≡

```

    if tmp_k1 ≠ null then
        begin wrapup(rt_hit); save_tail ← tail; tail_append(tmp_k1); goto main_loop_move;
    end

```

This code is used in sections 1209 and 1214.

1216. When a ligature or kern instruction matches a character, we know from *read_font.info* that the character exists in the font, even though we haven't verified its existence in the normal way.

This section could be made into a subroutine, if the code inside *main_control* needs to be shortened.

```

⟨ Do ligature or kern command, returning to main_lig_loop or main_loop_wrapup or main_loop_move 1216 ⟩ ≡
  begin if op_byte(main_j) ≥ kern_flag then
    begin wrapup(rt_hit); tail_append(new_kern(char_kern(main_f)(main_j))); goto main_loop_move;
  end;
  if cur_l = non_char then lft_hit ← true
  else if lig_stack = null then rt_hit ← true;
  check_interrupt; { allow a way out in case there's an infinite ligature loop }
  case op_byte(main_j) of
    qi(1), qi(5): begin cur_l ← rem_byte(main_j); { |=:|, |=:|> }
      main_i ← char_info(main_f)(cur_l); ligature_present ← true;
    end;
    qi(2), qi(6): begin cur_r ← rem_byte(main_j); { |=:, |=:> }
      if lig_stack = null then { right boundary character is being consumed }
        begin lig_stack ← new_lig_item(cur_r); bchar ← non_char;
      end
    else if is_char_node(lig_stack) then { link(lig_stack) = null }
      begin main_p ← lig_stack; lig_stack ← new_lig_item(cur_r); lig_ptr(lig_stack) ← main_p;
    end
    else character(lig_stack) ← cur_r;
  end;
  qi(3): begin cur_r ← rem_byte(main_j); { |=:| }
    main_p ← lig_stack; lig_stack ← new_lig_item(cur_r); link(lig_stack) ← main_p;
  end;
  qi(7), qi(11): begin wrapup(false); { |=:|>, |=:|>> }
    cur_q ← tail; cur_l ← rem_byte(main_j); main_i ← char_info(main_f)(cur_l);
    ligature_present ← true;
  end;
  othercases begin cur_l ← rem_byte(main_j); ligature_present ← true; { |=: }
    if lig_stack = null then goto main_loop_wrapup
    else goto main_loop_move + 1;
  end
endcases;
if op_byte(main_j) > qi(4) then
  if op_byte(main_j) ≠ qi(7) then goto main_loop_wrapup;
  if cur_l < non_char then goto main_lig_loop;
  main_k ← bchar_label[main_f]; goto main_lig_loop + 1;
end

```

This code is used in section 1214.

1217. The occurrence of blank spaces is almost part of TeX's inner loop, since we usually encounter about one space for every five non-blank characters. Therefore *main_control* gives second-highest priority to ordinary spaces.

When a glue parameter like `\spaceskip` is set to 'Opt', we will see to it later that the corresponding glue specification is precisely *zero_glue*, not merely a pointer to some specification that happens to be full of zeroes. Therefore it is simple to test whether a glue parameter is zero or not.

```

⟨Append a normal inter-word space to the current list, then goto big_switch 1217⟩ ≡
  if space_skip = zero_glue then
    begin ⟨Find the glue specification, main_p, for text spaces in the current font 1218⟩;
      temp_ptr ← new_glue(main_p);
    end
  else temp_ptr ← new_param_glue(space_skip_code);
  if pdf_adjust_interword_glue > 0 then adjust_interword_glue(tail, temp_ptr);
  link(tail) ← temp_ptr; tail ← temp_ptr; goto big_switch

```

This code is used in section 1205.

1218. Having *font_glue* allocated for each text font saves both time and memory. If any of the three spacing parameters are subsequently changed by the use of `\fontdimen`, the *find_font_dimen* procedure deallocates the *font_glue* specification allocated here.

```

⟨Find the glue specification, main_p, for text spaces in the current font 1218⟩ ≡
  begin main_p ← font_glue[cur_font];
  if main_p = null then
    begin main_p ← new_spec(zero_glue); main_k ← param_base[cur_font] + space_code;
      width(main_p) ← font_info[main_k].sc; { that's space(cur_font) }
      stretch(main_p) ← font_info[main_k + 1].sc; { and space_stretch(cur_font) }
      shrink(main_p) ← font_info[main_k + 2].sc; { and space_shrink(cur_font) }
      font_glue[cur_font] ← main_p;
    end;
  end

```

This code is used in sections 1217 and 1219.

```

1219. ⟨Declare action procedures for use by main_control 1219⟩ ≡
procedure app_space; { handle spaces when space_factor ≠ 1000 }
var q: pointer; { glue node }
begin if (space_factor ≥ 2000) ∧ (xspace_skip ≠ zero_glue) then q ← new_param_glue(xspace_skip_code)
else begin if space_skip ≠ zero_glue then main_p ← space_skip
  else ⟨Find the glue specification, main_p, for text spaces in the current font 1218⟩;
    main_p ← new_spec(main_p);
    ⟨Modify the glue specification in main_p according to the space factor 1220⟩;
    q ← new_glue(main_p); glue_ref_count(main_p) ← null;
  end;
  link(tail) ← q; tail ← q;
end;

```

See also sections 1223, 1225, 1226, 1227, 1230, 1236, 1237, 1240, 1245, 1246, 1251, 1255, 1260, 1262, 1267, 1269, 1271, 1272, 1275, 1277, 1279, 1281, 1286, 1289, 1293, 1295, 1299, 1303, 1305, 1307, 1311, 1312, 1314, 1318, 1327, 1331, 1335, 1336, 1339, 1341, 1348, 1350, 1352, 1357, 1367, 1370, 1376, 1387, 1446, 1451, 1455, 1464, 1469, 1478, 1526, and 1621.

This code is used in section 1205.

1220. \langle Modify the glue specification in *main_p* according to the space factor 1220 $\rangle \equiv$
if *space_factor* \geq 2000 **then** *width*(*main_p*) \leftarrow *width*(*main_p*) + *extra_space*(*cur_font*);
stretch(*main_p*) \leftarrow *xn_over_d*(*stretch*(*main_p*), *space_factor*, 1000);
shrink(*main_p*) \leftarrow *xn_over_d*(*shrink*(*main_p*), 1000, *space_factor*)

This code is used in section 1219.

1221. Whew—that covers the main loop. We can now proceed at a leisurely pace through the other combinations of possibilities.

define *any_mode*(#) \equiv *vmode* + #, *hmode* + #, *mmode* + # { for mode-independent commands }
 \langle Cases of *main_control* that are not part of the inner loop 1221 $\rangle \equiv$
any_mode(*relax*), *vmode* + *spacer*, *mmode* + *spacer*, *mmode* + *no_boundary*: *do_nothing*;
any_mode(*ignore_spaces*): **begin if** *cur_chr* = 0 **then**
 begin \langle Get the next non-blank non-call token 432 \rangle ;
 goto *reswitch*;
 end
else begin *t* \leftarrow *scanner_status*; *scanner_status* \leftarrow *normal*; *get_next*; *scanner_status* \leftarrow *t*;
 if *cur_cs* < *hash_base* **then** *cur_cs* \leftarrow *prim_lookup*(*cur_cs* - *single_base*)
 else *cur_cs* \leftarrow *prim_lookup*(*text*(*cur_cs*));
 if *cur_cs* \neq *undefined_primitive* **then**
 begin *cur_cmd* \leftarrow *prim_eq_type*(*cur_cs*); *cur_chr* \leftarrow *prim_equiv*(*cur_cs*);
 cur_tok \leftarrow *cs_token_flag* + *prim_eqtb_base* + *cur_cs*; **goto** *reswitch*;
 end;
 end;
end;
vmode + *stop*: **if** *its_all_over* **then return**; { this is the only way out }
 \langle Forbidden cases detected in *main_control* 1224 \rangle *any_mode*(*mac_param*): *report_illegal_case*;
 \langle Math-only cases in non-math modes, or vice versa 1222 \rangle : *insert_dollar_sign*;
 \langle Cases of *main_control* that build boxes and lists 1232 \rangle
 \langle Cases of *main_control* that don't depend on *mode* 1386 \rangle
 \langle Cases of *main_control* that are for extensions to TeX 1525 \rangle

This code is used in section 1205.

1222. Here is a list of cases where the user has probably gotten into or out of math mode by mistake. TeX will insert a dollar sign and rescan the current token.

define *non_math*(#) \equiv *vmode* + #, *hmode* + #
 \langle Math-only cases in non-math modes, or vice versa 1222 $\rangle \equiv$
non_math(*sup_mark*), *non_math*(*sub_mark*), *non_math*(*math_char_num*), *non_math*(*math_given*),
non_math(*math_comp*), *non_math*(*delim_num*), *non_math*(*left_right*), *non_math*(*above*),
non_math(*radical*), *non_math*(*math_style*), *non_math*(*math_choice*), *non_math*(*vcenter*),
non_math(*non_script*), *non_math*(*mkern*), *non_math*(*limit_switch*), *non_math*(*mskip*),
non_math(*math_accent*), *mmode* + *endv*, *mmode* + *par_end*, *mmode* + *stop*, *mmode* + *vskip*,
mmode + *un_vbox*, *mmode* + *valign*, *mmode* + *hrule*

This code is used in section 1221.

1223. \langle Declare action procedures for use by *main_control* 1219 \rangle + \equiv

procedure *insert_dollar_sign*;
 begin *back_input*; *cur_tok* \leftarrow *math_shift_token* + "\$"; *print_err*("Missing_\$_inserted");
 help2("I've inserted a begin-math/end-math symbol since I think")
 ("you left one out. Proceed, with fingers crossed."); *ins_error*;
 end;

1224. When erroneous situations arise, TeX usually issues an error message specific to the particular error. For example, ‘\noalign’ should not appear in any mode, since it is recognized by the *align_peek* routine in all of its legitimate appearances; a special error message is given when ‘\noalign’ occurs elsewhere. But sometimes the most appropriate error message is simply that the user is not allowed to do what he or she has attempted. For example, ‘\moveleft’ is allowed only in vertical mode, and ‘\lower’ only in non-vertical modes. Such cases are enumerated here and in the other sections referred to under ‘See also ...’

⟨Forbidden cases detected in *main_control* 1224⟩ ≡
 $vmode + vmove, hmode + hmove, mmode + hmove, any_mode(last_item),$

See also sections 1274, 1287, and 1320.

This code is used in section 1221.

1225. The ‘*you_cant*’ procedure prints a line saying that the current command is illegal in the current mode; it identifies these things symbolically.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
procedure you_cant;
begin print_err("You can't use "); print_cmd_chr(cur_cmd, cur_chr); print(" in ");
  print_mode(mode);
end;
```

1226. ⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
procedure report_illegal_case;
begin you_cant; help4("Sorry, but I'm not programmed to handle this case;")
  ("I'll just pretend that you didn't ask for it.")
  ("If you're in the wrong mode, you might be able to")
  ("return to the right one by typing `I` or `I$` or `I\par`.");
  error;
end;
```

1227. Some operations are allowed only in privileged modes, i.e., in cases that *mode* > 0. The *privileged* function is used to detect violations of this rule; it issues an error message and returns *false* if the current *mode* is negative.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
function privileged: boolean;
begin if mode > 0 then privileged ← true
else begin report_illegal_case; privileged ← false;
end;
end;
```

1228. Either \dump or \end will cause *main_control* to enter the endgame, since both of them have ‘*stop*’ as their command code.

⟨Put each of TeX’s primitives into the hash table 244⟩ +≡

```
primitive("end", stop, 0);
primitive("dump", stop, 1);
```

1229. ⟨Cases of *print_cmd_chr* for symbolic printing of primitives 245⟩ +≡

```
stop: if chr_code = 1 then print_esc("dump") else print_esc("end");
```

1230. We don't want to leave *main_control* immediately when a *stop* command is sensed, because it may be necessary to invoke an `\output` routine several times before things really grind to a halt. (The output routine might even say '`\gdef\end{...}`', to prolong the life of the job.) Therefore *its_all_over* is *true* only when the current page and contribution list are empty, and when the last output was not a "dead cycle."

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
function its_all_over: boolean; { do this when \end or \dump occurs }
  label exit;
  begin if privileged then
    begin if (page_head = page_tail) ∧ (head = tail) ∧ (dead_cycles = 0) then
      begin its_all_over ← true; return;
    end;
    back_input; { we will try to end again after ejecting residual material }
    tail_append(new_null_box); width(tail) ← hsize; tail_append(new_glue(fill_glue));
    tail_append(new_penalty(−'10000000000));
    build_page; { append \hbox to \hsize{}\vfill\penalty-'10000000000 }
    end;
    its_all_over ← false;
  exit: end;
```

1231. Building boxes and lists. The most important parts of *main_control* are concerned with TeX's chief mission of box-making. We need to control the activities that put entries on vlists and hlists, as well as the activities that convert those lists into boxes. All of the necessary machinery has already been developed; it remains for us to “push the buttons” at the right times.

1232. As an introduction to these routines, let's consider one of the simplest cases: What happens when ‘\hrule’ occurs in vertical mode, or ‘\vrule’ in horizontal mode or math mode? The code in *main_control* is short, since the *scan_rule_spec* routine already does most of what is required; thus, there is no need for a special action procedure.

Note that baselineskip calculations are disabled after a rule in vertical mode, by setting *prev_depth* ← *pdf_ignored_dimen*.

```
⟨ Cases of main_control that build boxes and lists 1232 ⟩ ≡
vmode + hrule, hmode + vrule, mmode + vrule: begin tail_append(scan_rule_spec);
  if abs(mode) = vmode then prev_depth ← pdf_ignored_dimen
  else if abs(mode) = hmode then space_factor ← 1000;
end;
```

See also sections 1233, 1239, 1243, 1249, 1266, 1268, 1270, 1273, 1278, 1280, 1285, 1288, 1292, 1298, 1302, 1306, 1310, 1313, 1316, 1326, 1330, 1334, 1338, 1340, 1343, 1347, 1351, 1356, 1366, and 1369.

This code is used in section 1221.

1233. The processing of things like \hskip and \vskip is slightly more complicated. But the code in *main_control* is very short, since it simply calls on the action routine *append_glue*. Similarly, \kern activates *append_kern*.

```
⟨ Cases of main_control that build boxes and lists 1232 ⟩ +≡
vmode + vskip, hmode + hskip, mmode + hskip, mmode + mskip: append_glue;
any_mode(kern), mmode + mkern: append_kern;
```

1234. The *hskip* and *vskip* command codes are used for control sequences like \hss and \vfil as well as for \hskip and \vskip. The difference is in the value of *cur_chr*.

```
define fil_code = 0 { identifies \hfil and \vfil }
define fill_code = 1 { identifies \hfill and \vfill }
define ss_code = 2 { identifies \hss and \vss }
define fil_neg_code = 3 { identifies \hfilneg and \vfilneg }
define skip_code = 4 { identifies \hskip and \vskip }
define mskip_code = 5 { identifies \mskip }

⟨ Put each of TeX's primitives into the hash table 244 ⟩ +≡
primitive("hskip", hskip, skip_code);
primitive("hfil", hskip, fil_code); primitive("hfill", hskip, fill_code);
primitive("hss", hskip, ss_code); primitive("hfilneg", hskip, fil_neg_code);
primitive("vskip", vskip, skip_code);
primitive("vfil", vskip, fil_code); primitive("vfill", vskip, fill_code);
primitive("vss", vskip, ss_code); primitive("vfilneg", vskip, fil_neg_code);
primitive("mskip", mskip, mskip_code);
primitive("kern", kern, explicit); primitive("mkern", mkern, mu_glue);
```

1235. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```

hskip: case chr_code of
  skip_code: print_esc("hskip");
  fil_code: print_esc("hfil");
  fill_code: print_esc("hfill");
  ss_code: print_esc("hss");
  othercases print_esc("hfilneg")
endcases;
vskip: case chr_code of
  skip_code: print_esc("vskip");
  fil_code: print_esc("vfil");
  fill_code: print_esc("vfill");
  ss_code: print_esc("vss");
  othercases print_esc("vfilneg")
endcases;
mskip: print_esc("mskip");
kern: print_esc("kern");
mkern: print_esc("mkern");

```

1236. All the work relating to glue creation has been relegated to the following subroutine. It does not call *build_page*, because it is used in at least one place where that would be a mistake.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure append_glue;
  var s: small_number; { modifier of skip command }
  begin s ← cur_chr;
  case s of
    fil_code: cur_val ← fil_glue;
    fill_code: cur_val ← fill_glue;
    ss_code: cur_val ← ss_glue;
    fil_neg_code: cur_val ← fil_neg_glue;
    skip_code: scan_glue(glue_val);
    mskip_code: scan_glue(mu_val);
  end; { now cur_val points to the glue specification }
  tail_append(new_glue(cur_val));
  if s ≥ skip_code then
    begin decr(glue_ref_count(cur_val));
    if s > skip_code then subtype(tail) ← mu_glue;
    end;
  end;
end;

```

1237. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure append_kern;
  var s: quarterword; { subtype of the kern node }
  begin s ← cur_chr; scan_dimen(s = mu_glue, false, false); tail_append(new_kern(cur_val));
  subtype(tail) ← s;
  end;
end;

```

1238. Many of the actions related to box-making are triggered by the appearance of braces in the input. For example, when the user says ‘\hbox to 100pt{hlist}’ in vertical mode, the information about the box size (100pt, *exactly*) is put onto *save_stack* with a level boundary word just above it, and *cur_group* ← *adjusted_hbox_group*; T_EX enters restricted horizontal mode to process the hlist. The right brace eventually causes *save_stack* to be restored to its former state, at which time the information about the box size (100pt, *exactly*) is available once again; a box is packaged and we leave restricted horizontal mode, appending the new box to the current list of the enclosing mode (in this case to the current list of vertical mode), followed by any vertical adjustments that were removed from the box by *hpack*.

The next few sections of the program are therefore concerned with the treatment of left and right curly braces.

1239. If a left brace occurs in the middle of a page or paragraph, it simply introduces a new level of grouping, and the matching right brace will not have such a drastic effect. Such grouping affects neither the mode nor the current list.

```

⟨Cases of main_control that build boxes and lists 1232⟩ +≡
non_math(left_brace): new_save_level(simple_group);
any_mode(begin_group): new_save_level(semi_simple_group);
any_mode(end_group): if cur_group = semi_simple_group then unsave
    else off_save;

```

1240. We have to deal with errors in which braces and such things are not properly nested. Sometimes the user makes an error of commission by inserting an extra symbol, but sometimes the user makes an error of omission. T_EX can’t always tell one from the other, so it makes a guess and tries to avoid getting into a loop.

The *off_save* routine is called when the current group code is wrong. It tries to insert something into the user’s input that will help clean off the top level.

```

⟨Declare action procedures for use by main_control 1219⟩ +≡
procedure off_save;
  var p: pointer; {inserted token}
  begin if cur_group = bottom_level then ⟨Drop current token and complain that it was unmatched 1242⟩
  else begin back_input; p ← get_avail; link(temp_head) ← p; print_err("Missing");
    ⟨Prepare to insert a token that matches cur_group, and print what it is 1241⟩;
    print("_inserted"); ins_list(link(temp_head));
    help5("I've inserted something that you may have forgotten.")
    ("(See the <inserted text> above.)")
    ("With luck, this will get me unwedged. But if you")
    ("really didn't forget anything, try typing `2' now; then")
    ("my insertion and my current dilemma will both disappear."); error;
  end;
end;

```

1241. At this point, $\text{link}(\text{temp.head}) = p$, a pointer to an empty one-word node.

⟨Prepare to insert a token that matches *cur_group*, and print what it is [1241](#)⟩ ≡

```

case cur_group of
  semi_simple_group: begin  $\text{info}(p) \leftarrow \text{cs\_token\_flag} + \text{frozen\_end\_group}$ ;  $\text{print\_esc}(\text{"endgroup"})$ ;
    end;
  math\_shift\_group: begin  $\text{info}(p) \leftarrow \text{math\_shift\_token} + \text{"\$"};$   $\text{print\_char}(\text{"\$"})$ ;
    end;
  math\_left\_group: begin  $\text{info}(p) \leftarrow \text{cs\_token\_flag} + \text{frozen\_right}$ ;  $\text{link}(p) \leftarrow \text{get\_avail}$ ;  $p \leftarrow \text{link}(p)$ ;
     $\text{info}(p) \leftarrow \text{other\_token} + \text{"."}$ ;  $\text{print\_esc}(\text{"right."})$ ;
    end;
othercases begin  $\text{info}(p) \leftarrow \text{right\_brace\_token} + \text{"}"$ ;  $\text{print\_char}(\text{"}"})$ ;
  end
endcases

```

This code is used in section [1240](#).

1242. ⟨Drop current token and complain that it was unmatched [1242](#)⟩ ≡

```

begin  $\text{print\_err}(\text{"Extra\_"})$ ;  $\text{print\_cmd\_chr}(\text{cur\_cmd}, \text{cur\_chr})$ ;
   $\text{help1}(\text{"Things\_are\_pretty\_mixed\_up,\_but\_I\_think\_the\_worst\_is\_over."})$ ;
   $\text{error}$ ;
end

```

This code is used in section [1240](#).

1243. The routine for a *right_brace* character branches into many subcases, since a variety of things may happen, depending on *cur_group*. Some types of groups are not supposed to be ended by a right brace; error messages are given in hopes of pinpointing the problem. Most branches of this routine will be filled in later, when we are ready to understand them; meanwhile, we must prepare ourselves to deal with such errors.

⟨Cases of *main_control* that build boxes and lists [1232](#)⟩ +≡

any_mode(right_brace): *handle_right_brace*;

1244. ⟨Declare the procedure called *handle_right_brace* [1244](#)⟩ ≡

```

procedure handle_right_brace;
  var p, q: pointer; { for short-term use }
    d: scaled; { holds split_max_depth in insert_group }
    f: integer; { holds floating_penalty in insert_group }
  begin case cur_group of
    simple_group: unsave;
    bottom_level: begin  $\text{print\_err}(\text{"Too\_many\_}\text{'s'}$ ");
       $\text{help2}(\text{"You've\_closed\_more\_groups\_than\_you\_opened."})$ 
       $(\text{"Such\_booboos\_are\_generally\_harmless,\_so\_keep\_going."})$ ;  $\text{error}$ ;
    end;
    semi_simple_group, math_shift_group, math_left_group: extra_right_brace;
  ⟨Cases of handle_right_brace where a right_brace triggers a delayed action 1261⟩
  othercases confusion("rightbrace")
  endcases;
end;

```

This code is used in section [1205](#).

1245. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure extra_right_brace;
begin print_err("Extra $\}$ , or forgotten $\}$ ");
case cur_group of
  semi_simple_group: print_esc("endgroup");
  math_shift_group: print_char("$");
  math_left_group: print_esc("right");
end;
help5("I've deleted a group-closing symbol because it seems to be")
("spurious, as in  $\$x\$\dot{}$ . But perhaps the  $\}$  is legitimate and")
("you forgot something else, as in  $\hbox{\$x}\dot{}$ . In such cases")
("the way to recover is to insert both the forgotten and the")
("deleted material, e.g., by typing  $\I\$\dot{}$ ."); error; incr(align_state);
end;
```

1246. Here is where we clear the parameters that are supposed to revert to their default values after every paragraph and when internal vertical mode is entered.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure normal_paragraph;
begin if looseness  $\neq$  0 then eq_word_define(int_base + looseness_code, 0);
if hang_indent  $\neq$  0 then eq_word_define(dimen_base + hang_indent_code, 0);
if hang_after  $\neq$  1 then eq_word_define(int_base + hang_after_code, 1);
if par_shape_ptr  $\neq$  null then eq_define(par_shape_loc, shape_ref, null);
if inter_line_penalties_ptr  $\neq$  null then eq_define(inter_line_penalties_loc, shape_ref, null);
end;
```

1247. Now let's turn to the question of how `\hbox` is treated. We actually need to consider also a slightly larger context, since constructions like `\setbox3=\hbox...` and `\leaders\hbox...` and `\lower3.8pt\hbox...` are supposed to invoke quite different actions after the box has been packaged. Conversely, constructions like `\setbox3=` can be followed by a variety of different kinds of boxes, and we would like to encode such things in an efficient way.

In other words, there are two problems: to represent the context of a box, and to represent its type.

The first problem is solved by putting a "context code" on the *save_stack*, just below the two entries that give the dimensions produced by *scan_spec*. The context code is either a (signed) shift amount, or it is a large integer $\geq \text{box_flag}$, where $\text{box_flag} = 2^{30}$. Codes box_flag through $\text{global_box_flag} - 1$ represent `\setbox0` through `\setbox32767`; codes global_box_flag through $\text{ship_out_flag} - 1$ represent `\global\setbox0` through `\global\setbox32767`; code ship_out_flag represents `\shipout`; and codes leader_flag through $\text{leader_flag} + 2$ represent `\leaders`, `\cleaders`, and `\xleaders`.

The second problem is solved by giving the command code *make_box* to all control sequences that produce a box, and by using the following *chr_code* values to distinguish between them: *box_code*, *copy_code*, *last_box_code*, *vsplit_code*, *vtop_code*, *vtop_code* + *vmode*, and *vtop_code* + *hmode*, where the latter two are used to denote `\vbox` and `\hbox`, respectively.

```
define box_flag ≡ '10000000000 { context code for '\setbox0' }
define global_box_flag ≡ '10000100000 { context code for '\global\setbox0' }
define ship_out_flag ≡ '10000200000 { context code for '\shipout' }
define leader_flag ≡ '10000200001 { context code for '\leaders' }
define box_code = 0 { chr_code for '\box' }
define copy_code = 1 { chr_code for '\copy' }
define last_box_code = 2 { chr_code for '\lastbox' }
define vsplit_code = 3 { chr_code for '\vsplit' }
define vtop_code = 4 { chr_code for '\vtop' }
```

(Put each of TeX's primitives into the hash table 244) +≡

```
primitive("moveleft", hmove, 1); primitive("moveright", hmove, 0);
primitive("raise", vmove, 1); primitive("lower", vmove, 0);

primitive("box", make_box, box_code); primitive("copy", make_box, copy_code);
primitive("lastbox", make_box, last_box_code); primitive("vsplit", make_box, vsplit_code);
primitive("vtop", make_box, vtop_code);
primitive("vbox", make_box, vtop_code + vmode); primitive("hbox", make_box, vtop_code + hmode);
primitive("shipout", leader_ship, a_leaders - 1); { ship_out_flag = leader_flag - 1 }
primitive("leaders", leader_ship, a_leaders); primitive("cleaders", leader_ship, c_leaders);
primitive("xleaders", leader_ship, x_leaders);
```

1248. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
hmove: **if** *chr_code* = 1 **then** *print_esc*("moveleft") **else** *print_esc*("moveright");
vmove: **if** *chr_code* = 1 **then** *print_esc*("raise") **else** *print_esc*("lower");
make_box: **case** *chr_code* **of**
 box_code: *print_esc*("box");
 copy_code: *print_esc*("copy");
 last_box_code: *print_esc*("lastbox");
 vsplit_code: *print_esc*("vsplit");
 vtop_code: *print_esc*("vtop");
 vtop_code + *vmode*: *print_esc*("vbox");
 othercases *print_esc*("hbox")
endcases;
leader_ship: **if** *chr_code* = *a_leaders* **then** *print_esc*("leaders")
 else if *chr_code* = *c_leaders* **then** *print_esc*("cleaders")
 else if *chr_code* = *x_leaders* **then** *print_esc*("xleaders")
 else *print_esc*("shipout");

1249. Constructions that require a box are started by calling *scan_box* with a specified context code. The *scan_box* routine verifies that a *make_box* command comes next and then it calls *begin_box*.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$
vmode + *hmove*, *hmode* + *vmove*, *mmode* + *vmove*: **begin** *t* \leftarrow *cur_chr*; *scan_normal_dimen*;
 if *t* = 0 **then** *scan_box*(*cur_val*) **else** *scan_box*($-cur_val$);
 end;
any_mode(*leader_ship*): *scan_box*(*leader_flag* - *a_leaders* + *cur_chr*);
any_mode(*make_box*): *begin_box*(0);

1250. The global variable *cur_box* will point to a newly made box. If the box is void, we will have *cur_box* = *null*. Otherwise we will have *type(cur_box)* = *hlist_node* or *vlist_node* or *rule_node*; the *rule_node* case can occur only with leaders.

\langle Global variables 13 $\rangle + \equiv$
cur_box: *pointer*; { box to be placed into its context }

1251. The *box_end* procedure does the right thing with *cur_box*, if *box_context* represents the context as explained above.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
procedure *box_end*(*box_context* : *integer*);
 var *p*: *pointer*; { *ord_noad* for new box in math mode }
 a: *small_number*; { global prefix }
 begin if *box_context* < *box_flag* **then**
 \langle Append box *cur_box* to the current list, shifted by *box_context* 1252 \rangle
 else if *box_context* < *ship_out_flag* **then** \langle Store *cur_box* in a box register 1253 \rangle
 else if *cur_box* \neq *null* **then**
 if *box_context* > *ship_out_flag* **then** \langle Append a new leader node that uses *cur_box* 1254 \rangle
 else *ship_out*(*cur_box*);
 end;

1252. The global variable *adjust_tail* will be non-null if and only if the current box might include adjustments that should be appended to the current vertical list.

⟨Append box *cur_box* to the current list, shifted by *box_context* 1252⟩ ≡

```

begin if cur_box ≠ null then
  begin shift_amount(cur_box) ← box_context;
  if abs(mode) = vmode then
    begin if pre_adjust_tail ≠ null then
      begin if pre_adjust_head ≠ pre_adjust_tail then append_list(pre_adjust_head)(pre_adjust_tail);
      pre_adjust_tail ← null;
    end;
    append_to_vlist(cur_box);
  if adjust_tail ≠ null then
    begin if adjust_head ≠ adjust_tail then append_list(adjust_head)(adjust_tail);
    adjust_tail ← null;
  end;
  if mode > 0 then build_page;
end
else begin if abs(mode) = hmode then space_factor ← 1000
  else begin p ← new_noad; math_type(nucleus(p)) ← sub_box; info(nucleus(p)) ← cur_box;
  cur_box ← p;
  end;
  link(tail) ← cur_box; tail ← cur_box;
end;
end;
end

```

This code is used in section 1251.

1253. ⟨Store *cur_box* in a box register 1253⟩ ≡

```

begin if box_context < global_box_flag then
  begin cur_val ← box_context − box_flag; a ← 0;
  end
else begin cur_val ← box_context − global_box_flag; a ← 4;
  end;
if cur_val < 256 then define(box_base + cur_val, box_ref, cur_box)
else sa_def_box;
end

```

This code is used in section 1251.

1254. ⟨Append a new leader node that uses *cur_box* 1254⟩ ≡

```

begin ⟨Get the next non-blank non-relax non-call token 430⟩;
if ((cur_cmd = hskip) ∧ (abs(mode) ≠ vmode)) ∨ ((cur_cmd = vskip) ∧ (abs(mode) = vmode)) then
  begin append_glue; subtype(tail) ← box_context − (leader_flag − a_leaders);
  leader_ptr(tail) ← cur_box;
  end
else begin print_err("Leaders_not_followed_by_proper_glue");
  help3("You_should_say`\\leaders<box_or_rule><hskip_or_vskip>`.")
  ("I_found_the<box_or_rule>,but_there's_no_suitable")
  ("<hskip_or_vskip>,so_I'm_ignoring_these_leaders."); back_error; flush_node_list(cur_box);
  end;
end

```

This code is used in section 1251.

1255. Now that we can see what eventually happens to boxes, we can consider the first steps in their creation. The *begin_box* routine is called when *box_context* is a context specification, *cur_chr* specifies the type of box desired, and *cur_cmd* = *make_box*.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
procedure begin_box(box_context : integer);
  label exit, done;
  var p, q: pointer; { run through the current list }
    r: pointer; { running behind p }
    fm: boolean; { a final \beginM \endM node pair? }
    tx: pointer; { effective tail node }
    m: quarterword; { the length of a replacement list }
    k: halfword; { 0 or vmode or hmode }
    n: halfword; { a box number }
  begin case cur_chr of
    box_code: begin scan_register_num; fetch_box(cur_box); change_box(null);
      { the box becomes void, at the same level }
    end;
    copy_code: begin scan_register_num; fetch_box(q); cur_box ← copy_node_list(q);
    end;
    last_box_code: ⟨If the current list ends with a box node, delete it from the list and make cur_box point to
      it; otherwise set cur_box ← null 1256⟩;
    vsplit_code: ⟨Split off part of a vertical box, make cur_box point to it 1258⟩;
    othercases ⟨Initiate the construction of an hbox or vbox, then return 1259⟩
  endcases;
  box_end(box_context); { in simple cases, we use the box immediately }
exit: end;
```

1256. Note that the condition $\neg is_char_node(tail)$ implies that $head \neq tail$, since $head$ is a one-word node.

```

define fetch_effective_tail_eTeX(#)  $\equiv$  { extract  $tx$ , drop \beginM \endM pair }
 $q \leftarrow head$ ;  $p \leftarrow null$ ;
repeat  $r \leftarrow p$ ;  $p \leftarrow q$ ;  $fm \leftarrow false$ ;
  if  $\neg is\_char\_node(q)$  then
    if  $type(q) = disc\_node$  then
      begin for  $m \leftarrow 1$  to  $replace\_count(q)$  do  $p \leftarrow link(p)$ ;
      if  $p = tx$  then #;
      end
    else if  $(type(q) = math\_node) \wedge (subtype(q) = begin\_M\_code)$  then  $fm \leftarrow true$ ;
     $q \leftarrow link(p)$ ;
  until  $q = tx$ ; { found  $r.p.q = tx$  }
 $q \leftarrow link(tx)$ ;  $link(p) \leftarrow q$ ;  $link(tx) \leftarrow null$ ;
if  $q = null$  then
  if  $fm$  then confusion("tail1")
  else  $tail \leftarrow p$ 
else if  $fm$  then {  $r.p = begin\_M.q = end\_M$  }
  begin  $tail \leftarrow r$ ;  $link(r) \leftarrow null$ ; flush_node_list( $p$ ); end
define check_effective_tail(#)  $\equiv find\_effective\_tail\_eTeX$ 
define fetch_effective_tail  $\equiv fetch\_effective\_tail\_eTeX$ 

```

(If the current list ends with a box node, delete it from the list and make cur_box point to it; otherwise set

```

 $cur\_box \leftarrow null$  1256)  $\equiv$ 
begin  $cur\_box \leftarrow null$ ;
if  $abs(mode) = mmode$  then
  begin you_cant; help1("Sorry; \_this\_lastbox\_will\_be\_void."); error;
  end
else if  $(mode = vmode) \wedge (head = tail)$  then
  begin you_cant; help2("Sorry...I\_usually\_can't\_take\_things\_from\_the\_current\_page.")
  ("This\_lastbox\_will\_therefore\_be\_void."); error;
  end
else begin check_effective_tail(goto done);
  if  $\neg is\_char\_node(tx)$  then
    if  $(type(tx) = hlist\_node) \vee (type(tx) = vlist\_node)$  then
      (Remove the last box, unless it's part of a discretionary 1257);
    done: end;
  end

```

This code is used in section 1255.

1257. (Remove the last box, unless it's part of a discretionary 1257) \equiv
begin *fetch_effective_tail*(**goto** *done*); $cur_box \leftarrow tx$; *shift_amount*(cur_box) $\leftarrow 0$;
end

This code is used in section 1256.

1258. Here we deal with things like ‘\vsplit 13 to 100pt’.

```

⟨Split off part of a vertical box, make cur_box point to it 1258⟩ ≡
  begin scan_register_num; n ← cur_val;
  if ¬scan_keyword("to") then
    begin print_err("Missing_ to_ inserted");
    help2("I'm_working_on_`\\vsplit<box_number>_to_<dimen>`");
    ("will_look_for_the_<dimen>_next."); error;
    end;
  scan_normal_dimen; cur_box ← vsplit(n, cur_val);
end

```

This code is used in section 1255.

1259. Here is where we enter restricted horizontal mode or internal vertical mode, in order to make a box.

```

⟨Initiate the construction of an hbox or vbox, then return 1259⟩ ≡
  begin k ← cur_chr - vtop_code; saved(0) ← box_context;
  if k = hmode then
    if (box_context < box_flag) ∧ (abs(mode) = vmode) then scan_spec(adjusted_hbox_group, true)
    else scan_spec(hbox_group, true)
  else begin if k = vmode then scan_spec(vbox_group, true)
    else begin scan_spec(vtop_group, true); k ← vmode;
    end;
    normal_paragraph;
    end;
  push_nest; mode ← -k;
  if k = vmode then
    begin prev_depth ← pdf_ignored_dimen;
    if every_vbox ≠ null then begin_token_list(every_vbox, every_vbox_text);
    end
  else begin space_factor ← 1000;
    if every_hbox ≠ null then begin_token_list(every_hbox, every_hbox_text);
    end;
  return;
end

```

This code is used in section 1255.

1260. ⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```

procedure scan_box(box_context : integer); { the next input should specify a box or perhaps a rule }
  begin ⟨Get the next non-blank non-relax non-call token 430⟩;
  if cur_cmd = make_box then begin_box(box_context)
  else if (box_context ≥ leader_flag) ∧ ((cur_cmd = hrule) ∨ (cur_cmd = vrule)) then
    begin cur_box ← scan_rule_spec; box_end(box_context);
    end
  else begin
    print_err("A_<box>_was_supposed_to_be_here");
    help3("I_was expecting_to_see_\\hbox_or_\\vbox_or_\\copy_or_\\box_or")
    ("something_like_that._So_you_might_find_something_missing_in")
    ("your_output._But_keep_trying;_you_can_fix_this_later."); back_error;
    end;
  end;

```

1261. When the right brace occurs at the end of an `\hbox` or `\vbox` or `\vtop` construction, the *package* routine comes into action. We might also have to finish a paragraph that hasn't ended.

⟨ Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261 ⟩ \equiv

```
hbox_group: package(0);
adjusted_hbox_group: begin adjust_tail  $\leftarrow$  adjust_head; pre_adjust_tail  $\leftarrow$  pre_adjust_head; package(0);
end;
vbox_group: begin end_graf; package(0);
end;
vtop_group: begin end_graf; package(vtop_code);
end;
```

See also sections 1276, 1294, 1308, 1309, 1344, 1349, and 1362.

This code is used in section 1244.

1262. ⟨ Declare action procedures for use by *main_control* 1219 ⟩ \equiv

```
procedure package(c : small_number);
  var h: scaled; { height of box }
      p: pointer; { first node in a box }
      d: scaled; { max depth }
  begin d  $\leftarrow$  box_max_depth; unsaved; save_ptr  $\leftarrow$  save_ptr - 3;
  if mode = -hmode then cur_box  $\leftarrow$  hpack(link(head), saved(2), saved(1))
  else begin cur_box  $\leftarrow$  vpackage(link(head), saved(2), saved(1), d);
    if c = vtop_code then ⟨ Readjust the height and depth of cur_box, for \vtop 1263 ⟩;
    end;
  pop_nest; box_end(saved(0));
end;
```

1263. The height of a ‘`\vtop`’ box is inherited from the first item on its list, if that item is an *hlist_node*, *vlist_node*, or *rule_node*; otherwise the `\vtop` height is zero.

⟨ Readjust the height and depth of *cur_box*, for \vtop 1263 ⟩ \equiv

```
begin h  $\leftarrow$  0; p  $\leftarrow$  list_ptr(cur_box);
if p  $\neq$  null then
  if type(p)  $\leq$  rule_node then h  $\leftarrow$  height(p);
  depth(cur_box)  $\leftarrow$  depth(cur_box) - h + height(cur_box); height(cur_box)  $\leftarrow$  h;
end
```

This code is used in section 1262.

1264. Here is a really small patch to add a new primitive called `\quitvmode`. In vertical modes, it is identical to `\indent`, but in horizontal and math modes it is really a no-op (as opposed to `\indent`, which executes the *indent_in_hmode* procedure).

A paragraph begins when horizontal-mode material occurs in vertical mode, or when the paragraph is explicitly started by ‘`\quitvmode`’, ‘`\indent`’ or ‘`\noindent`’.

⟨ Put each of TeX's primitives into the hash table 244 ⟩ \equiv

```
primitive("indent", start_par, 1); primitive("noindent", start_par, 0);
primitive("quitvmode", start_par, 2);
```

1265. ⟨ Cases of *print_cmd_chr* for symbolic printing of primitives 245 ⟩ \equiv

```
start_par: if chr_code = 0 then print_esc("noindent") else if chr_code = 1 then
  print_esc("indent") else print_esc("quitvmode");
```


1266. \langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```
vmode + start_par: new_graf(cur_chr > 0);
vmode + letter, vmode + other_char, vmode + char_num, vmode + char_given, vmode + math_shift,
    vmode + un_hbox, vmode + vrule, vmode + accent, vmode + discretionary, vmode + hskip,
    vmode + valign, vmode + ex_space, vmode + no_boundary:
  begin back_input; new_graf(true);
end;
```

1267. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
function norm_min(h : integer): small_number;
  begin if h ≤ 0 then norm_min ← 1 else if h ≥ 63 then norm_min ← 63 else norm_min ← h;
end;

procedure new_graf(indented : boolean);
  begin prev_graf ← 0;
  if (mode = vmode) ∨ (head ≠ tail) then tail_append(new_param_glue(par_skip_code));
  push_nest; mode ← hmode; space_factor ← 1000; set_cur_lang; clang ← cur_lang;
  prev_graf ← (norm_min(left_hyphen_min) * '100 + norm_min(right_hyphen_min)) * '200000 + cur_lang;
  if indented then
    begin tail ← new_null_box; link(head) ← tail; width(tail) ← par_indent; end;
  if every_par ≠ null then begin_token_list(every_par, every_par_text);
  if nest_ptr = 1 then build_page; { put par_skip glue on current page }
end;
```

1268. \langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```
hmode + start_par, mmode + start_par: if cur_chr ≠ 2 then indent_in_hmode;
```

1269. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure indent_in_hmode;
  var p, q: pointer;
  begin if cur_chr > 0 then { \indent }
    begin p ← new_null_box; width(p) ← par_indent;
    if abs(mode) = hmode then space_factor ← 1000
    else begin q ← new_noad; math_type(nucleus(q)) ← sub_box; info(nucleus(q)) ← p; p ← q;
    end;
    tail_append(p);
  end;
end;
```

1270. A paragraph ends when a *par_end* command is sensed, or when we are in horizontal mode when reaching the right brace of vertical-mode routines like *\vbox*, *\insert*, or *\output*.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```
vmode + par_end: begin normal_paragraph;
  if mode > 0 then build_page;
end;

hmode + par_end: begin if align_state < 0 then off_save;
  { this tries to recover from an alignment that didn't end properly }
  end_graf; { this takes us to the enclosing mode, if mode > 0 }
  if mode = vmode then build_page;
end;

hmode + stop, hmode + vskip, hmode + hrule, hmode + un_vbox, hmode + halign: head_for_vmode;
```

1271. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure head_for_vmode;
  begin if mode < 0 then
    if cur_cmd  $\neq$  hrule then off_save
    else begin print_err("You can't use `"); print_esc("hrule");
      print("`here except with leaders");
      help2("To put a horizontal rule in an hbox or an alignment,")
      ("you should use \leaders or \hrulefill (see The TeXbook)."); error;
    end
  else begin back_input; cur_tok  $\leftarrow$  par_token; back_input; token_type  $\leftarrow$  inserted;
  end;
end;

```

1272. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure end_graf;
  begin if mode = hmode then
    begin if head = tail then pop_nest { null paragraphs are ignored }
    else line_break(false);
    if LR_save  $\neq$  null then
      begin flush_list(LR_save); LR_save  $\leftarrow$  null;
      end;
    normal_paragraph; error_count  $\leftarrow$  0;
    end;
  end;

```

1273. Insertion and adjustment and mark nodes are constructed by the following pieces of the program.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

any_mode(*insert*), *hmode* + *vadjust*, *mmode* + *vadjust*: *begin_insert_or_adjust*;
any_mode(*mark*): *make_mark*;

1274. \langle Forbidden cases detected in *main_control* 1224 $\rangle + \equiv$

vmode + *vadjust*,

1275. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure begin_insert_or_adjust;
  begin if cur_cmd = vadjust then cur_val  $\leftarrow$  255
  else begin scan_eight_bit_int;
    if cur_val = 255 then
      begin print_err("You can't"); print_esc("insert"); print_int(255);
      help1("I'm changing to \insert0; box 255 is special."); error; cur_val  $\leftarrow$  0;
      end;
    end;
  saved(0)  $\leftarrow$  cur_val;
  if (cur_cmd = vadjust)  $\wedge$  scan_keyword("pre") then saved(1)  $\leftarrow$  1
  else saved(1)  $\leftarrow$  0;
  save_ptr  $\leftarrow$  save_ptr + 2; new_save_level(insert_group); scan_left_brace; normal_paragraph; push_nest;
  mode  $\leftarrow$   $-vmode$ ; prev_depth  $\leftarrow$  pdf_ignored_dimen;
end;

```

1276. \langle Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261 $\rangle + \equiv$
insert_group: **begin** *end_graf*; $q \leftarrow \text{split_top_skip}$; $\text{add_glue_ref}(q)$; $d \leftarrow \text{split_max_depth}$;
 $f \leftarrow \text{floating_penalty}$; *unsaved*; $\text{save_ptr} \leftarrow \text{save_ptr} - 2$;
 $\{ \text{now } \text{saved}(0) \text{ is the insertion number, or } 255 \text{ for } \text{vadjust} \}$
 $p \leftarrow \text{vpack}(\text{link}(\text{head}), \text{natural})$; pop_nest ;
if $\text{saved}(0) < 255$ **then**
 $\text{begin } \text{tail_append}(\text{get_node}(\text{ins_node_size}))$; $\text{type}(\text{tail}) \leftarrow \text{ins_node}$; $\text{subtype}(\text{tail}) \leftarrow \text{qi}(\text{saved}(0))$;
 $\text{height}(\text{tail}) \leftarrow \text{height}(p) + \text{depth}(p)$; $\text{ins_ptr}(\text{tail}) \leftarrow \text{list_ptr}(p)$; $\text{split_top_ptr}(\text{tail}) \leftarrow q$;
 $\text{depth}(\text{tail}) \leftarrow d$; $\text{float_cost}(\text{tail}) \leftarrow f$;
end
else begin $\text{tail_append}(\text{get_node}(\text{small_node_size}))$; $\text{type}(\text{tail}) \leftarrow \text{adjust_node}$;
 $\text{adjust_pre}(\text{tail}) \leftarrow \text{saved}(1)$; $\{ \text{the subtype is used for } \text{adjust_pre} \}$
 $\text{adjust_ptr}(\text{tail}) \leftarrow \text{list_ptr}(p)$; $\text{delete_glue_ref}(q)$;
end;
 $\text{free_node}(p, \text{box_node_size})$;
if $\text{nest_ptr} = 0$ **then** *build_page*;
end;
output_group: \langle Resume the page builder after an output routine has come to an end 1201 \rangle ;

1277. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
procedure *make_mark*;
 $\text{var } p$: *pointer*; $\{ \text{new node} \}$
 c : *halfword*; $\{ \text{the mark class} \}$
begin if $\text{cur_chr} = 0$ **then** $c \leftarrow 0$
else begin scan_register_num ; $c \leftarrow \text{cur_val}$;
end;
 $p \leftarrow \text{scan_toks}(\text{false}, \text{true})$; $p \leftarrow \text{get_node}(\text{small_node_size})$; $\text{mark_class}(p) \leftarrow c$; $\text{type}(p) \leftarrow \text{mark_node}$;
 $\text{subtype}(p) \leftarrow 0$; $\{ \text{the subtype is not used} \}$
 $\text{mark_ptr}(p) \leftarrow \text{def_ref}$; $\text{link}(\text{tail}) \leftarrow p$; $\text{tail} \leftarrow p$;
end;

1278. Penalty nodes get into a list via the *break_penalty* command.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$
any_mode(*break_penalty*): *append_penalty*;

1279. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
procedure *append_penalty*;
 $\text{begin } \text{scan_int}$; $\text{tail_append}(\text{new_penalty}(\text{cur_val}))$;
if $\text{mode} = \text{vmode}$ **then** *build_page*;
end;

1280. The *remove_item* command removes a penalty, kern, or glue node if it appears at the tail of the current list, using a brute-force linear scan. Like `\lastbox`, this command is not allowed in vertical mode (except internal vertical mode), since the current list in vertical mode is sent to the page builder. But if we happen to be able to implement it in vertical mode, we do.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$
any_mode(*remove_item*): *delete_last*;

1281. When *delete_last* is called, *cur_chr* is the *type* of node that will be deleted, if present.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```
procedure delete_last;
  label exit;
  var p, q: pointer; { run through the current list }
      r: pointer; { running behind p }
      fm: boolean; { a final \beginM \endM node pair? }
      tx: pointer; { effective tail node }
      m: quarterword; { the length of a replacement list }
  begin if (mode = vmode) ∧ (tail = head) then
    ⟨Apologize for inability to do the operation now, unless \unskip follows non-glue 1282⟩
  else begin check_effective_tail(return);
    if ¬is_char_node(tx) then
      if type(tx) = cur_chr then
        begin fetch_effective_tail(return); flush_node_list(tx);
        end;
      end;
    end;
exit: end;
```

1282. ⟨Apologize for inability to do the operation now, unless \unskip follows non-glue 1282⟩ ≡

```
begin if (cur_chr ≠ glue_node) ∨ (last_glue ≠ max_halfword) then
  begin you_cant; help2("Sorry... I usually can't take things from the current page.")
  ("Try \I\vskip-\lastskip instead.");
  if cur_chr = kern_node then help_line[0] ← ("Try \I\kern-\lastkern instead.")
  else if cur_chr ≠ glue_node then
    help_line[0] ← ("Perhaps you can make the output routine do it.");
  error;
  end;
end
```

This code is used in section 1281.

1283. ⟨Put each of TeX's primitives into the hash table 244⟩ +≡

```
primitive("unpenalty", remove_item, penalty_node);
primitive("unkern", remove_item, kern_node);
primitive("unskip", remove_item, glue_node);
primitive("unhbox", un_hbox, box_code);
primitive("unhcopy", un_hbox, copy_code);
primitive("unvbox", un_vbox, box_code);
primitive("unvcopy", un_vbox, copy_code);
```

1284. ⟨Cases of *print_cmd_chr* for symbolic printing of primitives 245⟩ +≡

```
remove_item: if chr_code = glue_node then print_esc("unskip")
  else if chr_code = kern_node then print_esc("unkern")
  else print_esc("unpenalty");
un_hbox: if chr_code = copy_code then print_esc("unhcopy")
  else print_esc("unhbox");
un_vbox: if chr_code = copy_code then print_esc("unvcopy") ⟨Cases of un_vbox for print_cmd_chr 1859⟩
  else print_esc("unvbox");
```

1285. The *un_hbox* and *un_vbox* commands unwrap one of the 256 current boxes.

⟨Cases of *main_control* that build boxes and lists 1232⟩ +≡

```
vmode + un_vbox, hmode + un_hbox, mmode + un_hbox: unpackage;
```

1286. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure unpackage;
  label done, exit;
  var p: pointer; { the box }
      r: pointer; { to remove marginal kern nodes }
      c: box_code .. copy_code; { should we copy? }
  begin if cur_chr > copy_code then  $\langle$  Handle saved items and goto done 1860  $\rangle$ ;
  c  $\leftarrow$  cur_chr; scan_register_num; fetch_box(p);
  if p = null then return;
  if (abs(mode) = mmode)  $\vee$  ((abs(mode) = vmode)  $\wedge$  (type(p)  $\neq$  vlist_node))  $\vee$ 
    ((abs(mode) = hmode)  $\wedge$  (type(p)  $\neq$  hlist_node)) then
    begin print_err("Incompatible_list_can't_be_unboxed");
    help3("Sorry, Pandora. (You sneaky devil.)")
    ("I_refuse_to_unbox_an_hbox_in_vertical_mode_or_vice_versa.")
    ("And I can't open any boxes in math mode.");
    error; return;
    end;
  if c = copy_code then link(tail)  $\leftarrow$  copy_node_list(list_ptr(p))
  else begin link(tail)  $\leftarrow$  list_ptr(p); change_box(null); free_node(p, box_node_size);
  end;
  done: while link(tail)  $\neq$  null do
    begin r  $\leftarrow$  link(tail);
    if  $\neg$ is_char_node(r)  $\wedge$  (type(r) = margin_kern_node) then
      begin link(tail)  $\leftarrow$  link(r); free_avail(margin_char(r)); free_node(r, margin_kern_node_size);
      end;
    tail  $\leftarrow$  link(tail);
    end;
  exit: end;

```

1287. \langle Forbidden cases detected in *main_control* 1224 $\rangle + \equiv$

vmode + ital_corr,

1288. Italic corrections are converted to kern nodes when the *ital_corr* command follows a character. In math mode the same effect is achieved by appending a kern of zero here, since italic corrections are supplied later.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

hmode + ital_corr: append_italic_correction;

mmode + ital_corr: tail_append(new_kern(0));

1289. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure append_italic_correction;
  label exit;
  var p: pointer; { char_node at the tail of the current list }
      f: internal_font_number; { the font in the char_node }
  begin if tail  $\neq$  head then
    begin if is_char_node(tail) then p  $\leftarrow$  tail
    else if type(tail) = ligature_node then p  $\leftarrow$  lig_char(tail)
    else return;
    f  $\leftarrow$  font(p); tail_append(new_kern(char_italic(f)(char_info(f)(character(p))));
    subtype(tail)  $\leftarrow$  explicit;
    end;
  exit: end;

```

1290. Discretionary nodes are easy in the common case ‘\-’, but in the general case we must process three braces full of items.

⟨ Put each of \TeX ’s primitives into the hash table 244 ⟩ +≡
 $\text{primitive}("-", \text{discretionary}, 1); \text{primitive}(\text{"discretionary"}, \text{discretionary}, 0);$

1291. ⟨ Cases of print_cmd_chr for symbolic printing of primitives 245 ⟩ +≡
 $\text{discretionary: if } \text{chr_code} = 1 \text{ then } \text{print_esc}("-") \text{ else } \text{print_esc}(\text{"discretionary"});$

1292. ⟨ Cases of main_control that build boxes and lists 1232 ⟩ +≡
 $\text{hmode} + \text{discretionary}, \text{mmode} + \text{discretionary: append_discretionary};$

1293. The space factor does not change when we append a discretionary node, but it starts out as 1000 in the subsidiary lists.

⟨ Declare action procedures for use by main_control 1219 ⟩ +≡
procedure $\text{append_discretionary};$
 $\text{var } c: \text{integer}; \quad \{ \text{hyphen character} \}$
begin $\text{tail_append}(\text{new_disc});$
if $\text{cur_chr} = 1$ **then**
 $\text{begin } c \leftarrow \text{hyphen_char}[\text{cur_font}];$
if $c \geq 0$ **then**
 $\text{if } c < 256 \text{ then } \text{pre_break}(\text{tail}) \leftarrow \text{new_character}(\text{cur_font}, c);$
end
else begin $\text{incr}(\text{save_ptr}); \text{saved}(-1) \leftarrow 0; \text{new_save_level}(\text{disc_group}); \text{scan_left_brace}; \text{push_nest};$
 $\text{mode} \leftarrow -\text{hmode}; \text{space_factor} \leftarrow 1000;$
end;
end;

1294. The three discretionary lists are constructed somewhat as if they were hboxes. A subroutine called $\text{build_discretionary}$ handles the transitions. (This is sort of fun.)

⟨ Cases of $\text{handle_right_brace}$ where a right_brace triggers a delayed action 1261 ⟩ +≡
 $\text{disc_group: build_discretionary};$

1295. ⟨ Declare action procedures for use by main_control 1219 ⟩ +≡
procedure $\text{build_discretionary};$
 $\text{label done, exit};$
 $\text{var } p, q: \text{pointer}; \quad \{ \text{for link manipulation} \}$
 $n: \text{integer}; \quad \{ \text{length of discretionary list} \}$
begin $\text{unsave};$
⟨ Prune the current list, if necessary, until it contains only char_node , kern_node , hlist_node , vlist_node , rule_node , and ligature_node items; set n to the length of the list, and set q to the list’s tail 1297 ⟩;
 $p \leftarrow \text{link}(\text{head}); \text{pop_nest};$
case $\text{saved}(-1)$ **of**
0: $\text{pre_break}(\text{tail}) \leftarrow p;$
1: $\text{post_break}(\text{tail}) \leftarrow p;$
2: ⟨ Attach list p to the current list, and record its length; then finish up and **return** 1296 ⟩;
end; { there are no other cases }
 $\text{incr}(\text{saved}(-1)); \text{new_save_level}(\text{disc_group}); \text{scan_left_brace}; \text{push_nest}; \text{mode} \leftarrow -\text{hmode};$
 $\text{space_factor} \leftarrow 1000;$
 $\text{exit: end};$

1296. \langle Attach list p to the current list, and record its length; then finish up and **return** 1296 $\rangle \equiv$

```

begin if ( $n > 0$ )  $\wedge$  ( $\text{abs}(\text{mode}) = \text{mmode}$ ) then
  begin  $\text{print\_err}(\text{"Illegal\_math\_"}); \text{print\_esc}(\text{"discretionary"});$ 
   $\text{help2}(\text{"Sorry: The third part of a discretionary break must be"})$ 
  ( $\text{"empty, in math formulas. I had to delete your third part."}$ );  $\text{flush\_node\_list}(p); n \leftarrow 0;$ 
   $\text{error};$ 
  end
else  $\text{link}(\text{tail}) \leftarrow p;$ 
if  $n \leq \text{max\_quarterword}$  then  $\text{replace\_count}(\text{tail}) \leftarrow n$ 
else begin  $\text{print\_err}(\text{"Discretionary\_list\_is\_too\_long"});$ 
   $\text{help2}(\text{"Wow---I never thought anybody would tweak me here."})$ 
  ( $\text{"You can't seriously need such a huge discretionary list?"}$ );  $\text{error};$ 
  end;
if  $n > 0$  then  $\text{tail} \leftarrow q;$ 
   $\text{decr}(\text{save\_ptr});$  return;
end

```

This code is used in section 1295.

1297. During this loop, $p = \text{link}(q)$ and there are n items preceding p .

\langle Prune the current list, if necessary, until it contains only *char_node*, *kern_node*, *hlist_node*, *vlist_node*, *rule_node*, and *ligature_node* items; set n to the length of the list, and set q to the list's tail 1297 $\rangle \equiv$

```

 $q \leftarrow \text{head}; p \leftarrow \text{link}(q); n \leftarrow 0;$ 
while  $p \neq \text{null}$  do
  begin if  $\neg \text{is\_char\_node}(p)$  then
    if  $\text{type}(p) > \text{rule\_node}$  then
      if  $\text{type}(p) \neq \text{kern\_node}$  then
        if  $\text{type}(p) \neq \text{ligature\_node}$  then
          begin  $\text{print\_err}(\text{"Improper\_discretionary\_list"});$ 
           $\text{help1}(\text{"Discretionary\_lists\_must\_contain\_only\_boxes\_and\_kerns."});$ 
           $\text{error}; \text{begin\_diagnostic};$ 
           $\text{print\_nl}(\text{"The\_following\_discretionary\_sublist\_has\_been\_deleted:"}); \text{show\_box}(p);$ 
           $\text{end\_diagnostic}(\text{true}); \text{flush\_node\_list}(p); \text{link}(q) \leftarrow \text{null}; \text{goto done};$ 
          end;
         $q \leftarrow p; p \leftarrow \text{link}(q); \text{incr}(n);$ 
      end;

```

done:

This code is used in section 1295.

1298. We need only one more thing to complete the horizontal mode routines, namely the `\accent` primitive.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```

 $\text{hmode} + \text{accent: make\_accent};$ 

```

1299. The positioning of accents is straightforward but tedious. Given an accent of width a , designed for characters of height x and slant s ; and given a character of width w , height h , and slant t : We will shift the accent down by $x - h$, and we will insert kern nodes that have the effect of centering the accent over the character and shifting the accent to the right by $\delta = \frac{1}{2}(w - a) + h \cdot t - x \cdot s$. If either character is absent from the font, we will simply use the other, without shifting.

⟨ Declare action procedures for use by *main_control* 1219 ⟩ \equiv

```
procedure make_accent;
  var  $s, t$ : real; { amount of slant }
   $p, q, r$ : pointer; { character, box, and kern nodes }
   $f$ : internal_font_number; { relevant font }
   $a, h, x, w, \delta$ : scaled; { heights and widths, as explained above }
   $i$ : four_quarters; { character information }
begin scan_char_num;  $f \leftarrow \text{cur\_font}$ ;  $p \leftarrow \text{new\_character}(f, \text{cur\_val})$ ;
if  $p \neq \text{null}$  then
  begin  $x \leftarrow x.\text{height}(f)$ ;  $s \leftarrow \text{slant}(f)/\text{float\_constant}(65536)$ ;
   $a \leftarrow \text{char\_width}(f)(\text{char\_info}(f)(\text{character}(p)))$ ;
  do\_assignments;
  ⟨ Create a character node  $q$  for the next character, but set  $q \leftarrow \text{null}$  if problems arise 1300 ⟩;
  if  $q \neq \text{null}$  then ⟨ Append the accent with appropriate kerns, then set  $p \leftarrow q$  1301 ⟩;
   $\text{link}(\text{tail}) \leftarrow p$ ;  $\text{tail} \leftarrow p$ ;  $\text{space\_factor} \leftarrow 1000$ ;
  end;
end;
```

1300. ⟨ Create a character node q for the next character, but set $q \leftarrow \text{null}$ if problems arise 1300 ⟩ \equiv

```
 $q \leftarrow \text{null}$ ;  $f \leftarrow \text{cur\_font}$ ;
if  $(\text{cur\_cmd} = \text{letter}) \vee (\text{cur\_cmd} = \text{other\_char}) \vee (\text{cur\_cmd} = \text{char\_given})$  then
   $q \leftarrow \text{new\_character}(f, \text{cur\_chr})$ 
else if  $\text{cur\_cmd} = \text{char\_num}$  then
  begin scan_char_num;  $q \leftarrow \text{new\_character}(f, \text{cur\_val})$ ;
  end
else back\_input
```

This code is used in section 1299.

1301. The kern nodes appended here must be distinguished from other kerns, lest they be wiped away by the hyphenation algorithm or by a previous line break.

The two kerns are computed with (machine-dependent) *real* arithmetic, but their sum is machine-independent; the net effect is machine-independent, because the user cannot remove these nodes nor access them via `\lastkern`.

⟨ Append the accent with appropriate kerns, then set $p \leftarrow q$ 1301 ⟩ \equiv

```
begin  $t \leftarrow \text{slant}(f)/\text{float\_constant}(65536)$ ;  $i \leftarrow \text{char\_info}(f)(\text{character}(q))$ ;  $w \leftarrow \text{char\_width}(f)(i)$ ;
 $h \leftarrow \text{char\_height}(f)(\text{height\_depth}(i))$ ;
if  $h \neq x$  then { the accent must be shifted up or down }
  begin  $p \leftarrow \text{hpack}(p, \text{natural})$ ;  $\text{shift\_amount}(p) \leftarrow x - h$ ;
  end;
 $\delta \leftarrow \text{round}((w - a)/\text{float\_constant}(2) + h * t - x * s)$ ;  $r \leftarrow \text{new\_kern}(\delta)$ ;  $\text{subtype}(r) \leftarrow \text{acc\_kern}$ ;
 $\text{link}(\text{tail}) \leftarrow r$ ;  $\text{link}(r) \leftarrow p$ ;  $\text{tail} \leftarrow \text{new\_kern}(-a - \delta)$ ;  $\text{subtype}(\text{tail}) \leftarrow \text{acc\_kern}$ ;  $\text{link}(p) \leftarrow \text{tail}$ ;
 $p \leftarrow q$ ;
end
```

This code is used in section 1299.

1302. When ‘\cr’ or ‘\span’ or a tab mark comes through the scanner into *main_control*, it might be that the user has foolishly inserted one of them into something that has nothing to do with alignment. But it is far more likely that a left brace or right brace has been omitted, since *get_next* takes actions appropriate to alignment only when ‘\cr’ or ‘\span’ or tab marks occur with *align_state* = 0. The following program attempts to make an appropriate recovery.

⟨ Cases of *main_control* that build boxes and lists 1232 ⟩ +≡

```
any_mode(car_ret), any_mode(tab_mark): align_error;
any_mode(no_align): no_align_error;
any_mode(omit): omit_error;
```

1303. ⟨ Declare action procedures for use by *main_control* 1219 ⟩ +≡

```
procedure align_error;
  begin if abs(align_state) > 2 then
    ⟨ Express consternation over the fact that no alignment is in progress 1304 ⟩
  else begin back_input;
    if align_state < 0 then
      begin print_err("Missing_{inserted}"); incr(align_state); cur_tok ← left_brace_token + "{";
      end
    else begin print_err("Missing_{inserted}"); decr(align_state); cur_tok ← right_brace_token + "}";
      end;
    help3("I've put in what seems to be necessary to fix")
    ("the current column of the current alignment.")
    ("Try to go on, since this might almost work."); ins_error;
    end;
  end;
```

1304. ⟨ Express consternation over the fact that no alignment is in progress 1304 ⟩ ≡

```
begin print_err("Misplaced"); print_cmd_chr(cur_cmd, cur_chr);
if cur_tok = tab_token + "&" then
  begin help6("I can't figure out why you would want to use a tab mark")
    ("here. If you just want an ampersand, the remedy is")
    ("simple: Just type `I&` now. But if some right brace")
    ("up above has ended a previous alignment prematurely,")
    ("you're probably due for more error messages, and you")
    ("might try typing `S` now just to see what is salvageable.");
  end
else begin help5("I can't figure out why you would want to use a tab mark")
  ("or \cr or \span just now. If something like a right brace")
  ("up above has ended a previous alignment prematurely,")
  ("you're probably due for more error messages, and you")
  ("might try typing `S` now just to see what is salvageable.");
  end;
error;
end
```

This code is used in section 1303.

1305. The help messages here contain a little white lie, since `\noalign` and `\omit` are allowed also after `'\noalign{...}'`.

```
<Declare action procedures for use by main_control 1219> +≡
procedure no_align_error;
  begin print_err("Misplaced_"); print_esc("noalign");
  help2("I_expect_to_see_\noalign_only_after_the_cr_of")
  ("an_alignment. Proceed, and I'll ignore this case."); error;
end;
procedure omit_error;
  begin print_err("Misplaced_"); print_esc("omit");
  help2("I_expect_to_see_\omit_only_after_tab_marks_or_the_cr_of")
  ("an_alignment. Proceed, and I'll ignore this case."); error;
end;
```

1306. We've now covered most of the abuses of `\halign` and `\valign`. Let's take a look at what happens when they are used correctly.

```
<Cases of main_control that build boxes and lists 1232> +≡
vmode + halign: init_align;
hmode + valign: <Cases of main_control for hmode + valign 1700>
  init_align;
mmode + halign: if privileged then
  if cur_group = math_shift_group then init_align
  else off_save;
vmode + endv, hmode + endv: do_endv;
```

1307. An *align_group* code is supposed to remain on the *save_stack* during an entire alignment, until *fin_align* removes it.

A devious user might force an *endv* command to occur just about anywhere; we must defeat such hacks.

```
<Declare action procedures for use by main_control 1219> +≡
procedure do_endv;
  begin base_ptr ← input_ptr; input_stack[base_ptr] ← cur_input;
  while (input_stack[base_ptr].index_field ≠ v_template) ∧ (input_stack[base_ptr].loc_field =
    null) ∧ (input_stack[base_ptr].state_field = token_list) do decr(base_ptr);
  if (input_stack[base_ptr].index_field ≠ v_template) ∨ (input_stack[base_ptr].loc_field ≠
    null) ∨ (input_stack[base_ptr].state_field ≠ token_list) then
    fatal_error("(interwoven_alignment_preambles_are_not_allowed)");
  if cur_group = align_group then
    begin end_graf;
    if fin_col then fin_row;
    end
  else off_save;
end;
```

1308. <Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261> +≡
align_group: **begin** *back_input*; *cur_tok* ← *cs_token_flag* + *frozen_cr*; *print_err*("Missing_");
print_esc("cr"); *print*("_inserted");
help1("I'm_guessing_that_you_meant_to_end_an_alignment_here."); *ins_error*;
end;

1309. \langle Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261 $\rangle + \equiv$
no_align_group: **begin** *end_graf*; *unsave*; *align_peek*;
end;

1310. Finally, `\endcsname` is not supposed to get through to *main_control*.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$
any_mode(*end_cs_name*): *cs_error*;

1311. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

procedure *cs_error*;
begin *print_err*("Extra_"); *print_esc*("endcsname");
help1("I'm ignoring this, since I wasn't doing a \csname."); *error*;
end;

1312. Building math lists. The routines that TeX uses to create mlists are similar to those we have just seen for the generation of hlists and vlists. But it is necessary to make “noads” as well as nodes, so the reader should review the discussion of math mode data structures before trying to make sense out of the following program.

Here is a little routine that needs to be done whenever a subformula is about to be processed. The parameter is a code like *math_group*.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

procedure *push_math*(*c* : *group_code*);

begin *push_nest*; *mode* ← −*mmode*; *incompleteat_noad* ← *null*; *new_save_level*(*c*);

end;

1313. We get into math mode from horizontal mode when a ‘\$’ (i.e., a *math_shift* character) is scanned. We must check to see whether this ‘\$’ is immediately followed by another, in case display math mode is called for.

⟨Cases of *main_control* that build boxes and lists 1232⟩ +≡

hmode + *math_shift*: *init_math*;

1314. ⟨Declare action procedures for use by *main_control* 1219⟩ +≡

⟨Declare subprocedures for *init_math* 1730⟩

procedure *init_math*;

label *reswitch*, *found*, *not_found*, *done*;

var *w*: *scaled*; { new or partial *pre_display_size* }

j: *pointer*; { prototype box for display }

x: *integer*; { new *pre_display_direction* }

l: *scaled*; { new *display_width* }

s: *scaled*; { new *display_indent* }

p: *pointer*; { current node when calculating *pre_display_size* }

q: *pointer*; { glue specification when calculating *pre_display_size* }

f: *internal_font_number*; { font in current *char_node* }

n: *integer*; { scope of paragraph shape specification }

v: *scaled*; { *w* plus possible glue amount }

d: *scaled*; { increment to *v* }

begin *get_token*; { *get_x_token* would fail on `\ifmmode!` }

if (*cur_cmd* = *math_shift*) ∧ (*mode* > 0) **then** ⟨Go into display math mode 1321⟩

else begin *back_input*; ⟨Go into ordinary math mode 1315⟩;

end;

end;

1315. ⟨Go into ordinary math mode 1315⟩ ≡

begin *push_math*(*math_shift_group*); *eq_word_define*(*int_base* + *cur_fam_code*, −1);

if *every_math* ≠ *null* **then** *begin_token_list*(*every_math*, *every_math_text*);

end

This code is used in sections 1314 and 1318.

1316. We get into ordinary math mode from display math mode when ‘\eqno’ or ‘\leqno’ appears. In such cases *cur_chr* will be 0 or 1, respectively; the value of *cur_chr* is placed onto *save_stack* for safe keeping.

⟨Cases of *main_control* that build boxes and lists 1232⟩ +≡

mmode + *eq_no*: **if** *privileged* **then**

if *cur_group* = *math_shift_group* **then** *start_eq_no*

else *off_save*;

1317. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$
`primitive("eqno", eq_no, 0); primitive("leqno", eq_no, 1);`

1318. When TeX is in display math mode, *cur_group* = *math_shift_group*, so it is not necessary for the *start_eq_no* procedure to test for this condition.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

procedure *start_eq_no*;

begin *saved*(0) \leftarrow *cur_chr*; *incr*(*save_ptr*); \langle Go into ordinary math mode 1315 \rangle ;
end;

1319. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
`eq_no: if chr_code = 1 then print_esc("leqno") else print_esc("eqno");`

1320. \langle Forbidden cases detected in *main_control* 1224 $\rangle + \equiv$
`non_math(eq_no),`

1321. When we enter display math mode, we need to call *line_break* to process the partial paragraph that has just been interrupted by the display. Then we can set the proper values of *display_width* and *display_indent* and *pre_display_size*.

\langle Go into display math mode 1321 $\rangle \equiv$

begin *j* \leftarrow *null*; *w* \leftarrow $-max_dimen$;

if *head* = *tail* **then** { '\noindent\$\$' or '\$\$ \$\$' }

\langle Prepare for display after an empty paragraph 1729 \rangle

else begin *line_break*(*true*);

\langle Calculate the natural width, *w*, by which the characters of the final line extend to the right of the reference point, plus two ems; or set *w* \leftarrow *max_dimen* if the non-blank information on that line is affected by stretching or shrinking 1322 \rangle ;

end; { now we are in vertical mode, working on the list that will contain the display }

\langle Calculate the length, *l*, and the shift amount, *s*, of the display lines 1325 \rangle ;

push_math(*math_shift_group*); *mode* \leftarrow *mmode*; *eq_word_define*(*int_base* + *cur_fam_code*, -1);

eq_word_define(*dimen_base* + *pre_display_size_code*, *w*); *LR_box* \leftarrow *j*;

if *eTeX_ex* **then** *eq_word_define*(*int_base* + *pre_display_direction_code*, *x*);

eq_word_define(*dimen_base* + *display_width_code*, *l*); *eq_word_define*(*dimen_base* + *display_indent_code*, *s*);

if *every_display* \neq *null* **then** *begin_token_list*(*every_display*, *every_display_text*);

if *nest_ptr* = 1 **then** *build_page*;

end

This code is used in section 1314.

1322. \langle Calculate the natural width, w , by which the characters of the final line extend to the right of the reference point, plus two ems; or set $w \leftarrow \text{max_dimen}$ if the non-blank information on that line is affected by stretching or shrinking [1322](#) $\rangle \equiv$

```

 $\langle$  Prepare for display after a non-empty paragraph 1731  $\rangle$ ;
while  $p \neq \text{null}$  do
  begin  $\langle$  Let  $d$  be the natural width of node  $p$ ; if the node is “visible,” goto found; if the node is glue
    that stretches or shrinks, set  $v \leftarrow \text{max\_dimen}$  1323  $\rangle$ ;
  if  $v < \text{max\_dimen}$  then  $v \leftarrow v + d$ ;
  goto not_found;
found: if  $v < \text{max\_dimen}$  then
  begin  $v \leftarrow v + d$ ;  $w \leftarrow v$ ;
  end
  else begin  $w \leftarrow \text{max\_dimen}$ ; goto done;
  end;
not_found:  $p \leftarrow \text{link}(p)$ ;
end;
done:  $\langle$  Finish the natural width computation 1732  $\rangle$ 

```

This code is used in section [1321](#).

1323. \langle Let d be the natural width of node p ; if the node is “visible,” **goto** *found*; if the node is glue that stretches or shrinks, set $v \leftarrow \text{max_dimen}$ [1323](#) $\rangle \equiv$

```

reswitch: if is_char_node( $p$ ) then
  begin  $f \leftarrow \text{font}(p)$ ;  $d \leftarrow \text{char\_width}(f)(\text{char\_info}(f)(\text{character}(p)))$ ; goto found;
  end;
case type( $p$ ) of
  hlist_node, vlist_node, rule_node: begin  $d \leftarrow \text{width}(p)$ ; goto found;
  end;
ligature_node:  $\langle$  Make node  $p$  look like a char_node and goto reswitch 824  $\rangle$ ;
margin_kern_node:  $d \leftarrow \text{width}(p)$ ;
kern_node:  $d \leftarrow \text{width}(p)$ ;
 $\langle$  Cases of ‘Let  $d$  be the natural width’ that need special treatment 1733  $\rangle$ 
glue_node:  $\langle$  Let  $d$  be the natural width of this glue; if stretching or shrinking, set  $v \leftarrow \text{max\_dimen}$ ; goto
  found in the case of leaders 1324  $\rangle$ ;
whatsit_node:  $\langle$  Let  $d$  be the width of the whatsit  $p$  1605  $\rangle$ ;
othercases  $d \leftarrow 0$ 
endcases

```

This code is used in section [1322](#).

1324. We need to be careful that w , v , and d do not depend on any *glue_set* values, since such values are subject to system-dependent rounding. System-dependent numbers are not allowed to infiltrate parameters like *pre_display_size*, since TeX82 is supposed to make the same decisions on all machines.

⟨ Let d be the natural width of this glue; if stretching or shrinking, set $v \leftarrow \text{max_dimen}$; **goto** *found* in the case of leaders 1324 ⟩ \equiv

```

begin  $q \leftarrow \text{glue\_ptr}(p)$ ;  $d \leftarrow \text{width}(q)$ ;
if  $\text{glue\_sign}(\text{just\_box}) = \text{stretching}$  then
  begin if  $(\text{glue\_order}(\text{just\_box}) = \text{stretch\_order}(q)) \wedge (\text{stretch}(q) \neq 0)$  then  $v \leftarrow \text{max\_dimen}$ ;
  end
else if  $\text{glue\_sign}(\text{just\_box}) = \text{shrinking}$  then
  begin if  $(\text{glue\_order}(\text{just\_box}) = \text{shrink\_order}(q)) \wedge (\text{shrink}(q) \neq 0)$  then  $v \leftarrow \text{max\_dimen}$ ;
  end;
if  $\text{subtype}(p) \geq \text{a\_leaders}$  then goto found;
end

```

This code is used in section 1323.

1325. A displayed equation is considered to be three lines long, so we calculate the length and offset of line number *prev_graf* + 2.

⟨ Calculate the length, l , and the shift amount, s , of the display lines 1325 ⟩ \equiv

```

if  $\text{par\_shape\_ptr} = \text{null}$  then
  if  $(\text{hang\_indent} \neq 0) \wedge (((\text{hang\_after} \geq 0) \wedge (\text{prev\_graf} + 2 > \text{hang\_after})) \vee$ 
     $(\text{prev\_graf} + 1 < -\text{hang\_after}))$  then
    begin  $l \leftarrow \text{hsize} - \text{abs}(\text{hang\_indent})$ ;
    if  $\text{hang\_indent} > 0$  then  $s \leftarrow \text{hang\_indent}$  else  $s \leftarrow 0$ ;
    end
  else begin  $l \leftarrow \text{hsize}$ ;  $s \leftarrow 0$ ;
  end
else begin  $n \leftarrow \text{info}(\text{par\_shape\_ptr})$ ;
  if  $\text{prev\_graf} + 2 \geq n$  then  $p \leftarrow \text{par\_shape\_ptr} + 2 * n$ 
  else  $p \leftarrow \text{par\_shape\_ptr} + 2 * (\text{prev\_graf} + 2)$ ;
   $s \leftarrow \text{mem}[p - 1].\text{sc}$ ;  $l \leftarrow \text{mem}[p].\text{sc}$ ;
  end

```

This code is used in section 1321.

1326. Subformulas of math formulas cause a new level of math mode to be entered, on the semantic nest as well as the save stack. These subformulas arise in several ways: (1) A left brace by itself indicates the beginning of a subformula that will be put into a box, thereby freezing its glue and preventing line breaks. (2) A subscript or superscript is treated as a subformula if it is not a single character; the same applies to the nucleus of things like `\underline`. (3) The `\left` primitive initiates a subformula that will be terminated by a matching `\right`. The group codes placed on *save_stack* in these three cases are *math_group*, *math_group*, and *math_left_group*, respectively.

Here is the code that handles case (1); the other cases are not quite as trivial, so we shall consider them later.

⟨ Cases of *main_control* that build boxes and lists 1232 ⟩ $+\equiv$

```

 $\text{mmode} + \text{left\_brace}$ : begin  $\text{tail\_append}(\text{new\_noad})$ ;  $\text{back\_input}$ ;  $\text{scan\_math}(\text{nucleus}(\text{tail}))$ ;
end;

```

1327. Recall that the *nucleus*, *subscr*, and *supscr* fields in a *noad* are broken down into subfields called *math_type* and either *info* or (*fam*, *character*). The job of *scan_math* is to figure out what to place in one of these principal fields; it looks at the subformula that comes next in the input, and places an encoding of that subformula into a given word of *mem*.

```

define fam_in_range  $\equiv ((cur\_fam \geq 0) \wedge (cur\_fam < 16))$ 
⟨Declare action procedures for use by main_control 1219⟩ +=
procedure scan_math(p : pointer);
  label restart, reswitch, exit;
  var c: integer; { math character code }
  begin restart: ⟨Get the next non-blank non-relax non-call token 430⟩;
reswitch: case cur_cmd of
  letter, other_char, char_given: begin c  $\leftarrow$  ho(math_code(cur_chr));
    if c = '100000 then
      begin ⟨Treat cur_chr as an active character 1328⟩;
      goto restart;
    end;
  end;
  char_num: begin scan_char_num; cur_chr  $\leftarrow$  cur_val; cur_cmd  $\leftarrow$  char_given; goto reswitch;
  end;
  math_char_num: begin scan_fifteen_bit_int; c  $\leftarrow$  cur_val;
  end;
  math_given: c  $\leftarrow$  cur_chr;
  delim_num: begin scan_twenty_seven_bit_int; c  $\leftarrow$  cur_val div '10000;
  end;
  othercases ⟨Scan a subformula enclosed in braces and return 1329⟩
endcases;
  math_type(p)  $\leftarrow$  math_char; character(p)  $\leftarrow$  qi(c mod 256);
  if (c  $\geq$  var_code)  $\wedge$  fam_in_range then fam(p)  $\leftarrow$  cur_fam
  else fam(p)  $\leftarrow$  (c div 256) mod 16;
exit: end;

```

1328. An active character that is an *outer_call* is allowed here.

```

⟨Treat cur_chr as an active character 1328⟩  $\equiv$ 
begin cur_cs  $\leftarrow$  cur_chr + active_base; cur_cmd  $\leftarrow$  eq_type(cur_cs); cur_chr  $\leftarrow$  equiv(cur_cs); x_token;
  back_input;
end

```

This code is used in sections 1327 and 1331.

1329. The pointer *p* is placed on *save_stack* while a complex subformula is being scanned.

```

⟨Scan a subformula enclosed in braces and return 1329⟩  $\equiv$ 
begin back_input; scan_left_brace;
  saved(0)  $\leftarrow$  p; incr(save_ptr); push_math(math_group); return;
end

```

This code is used in section 1327.

1330. The simplest math formula is, of course, ‘\$ \$’, when no noads are generated. The next simplest cases involve a single character, e.g., ‘\$x\$’. Even though such cases may not seem to be very interesting, the reader can perhaps understand how happy the author was when ‘\$x\$’ was first properly typeset by TeX. The code in this section was used.

```

⟨Cases of main_control that build boxes and lists 1232⟩ +≡
mmode + letter, mmode + other_char, mmode + char_given: set_math_char(ho(math_code(cur_chr)));
mmode + char_num: begin scan_char_num; cur_chr ← cur_val; set_math_char(ho(math_code(cur_chr)));
end;
mmode + math_char_num: begin scan_fifteen_bit_int; set_math_char(cur_val);
end;
mmode + math_given: set_math_char(cur_chr);
mmode + delim_num: begin scan_twenty_seven_bit_int; set_math_char(cur_val div '10000);
end;

```

1331. The *set_math_char* procedure creates a new noad appropriate to a given math code, and appends it to the current mlist. However, if the math code is sufficiently large, the *cur_chr* is treated as an active character and nothing is appended.

```

⟨Declare action procedures for use by main_control 1219⟩ +≡
procedure set_math_char(c : integer);
  var p: pointer; { the new noad }
  begin if c ≥ '100000 then ⟨Treat cur_chr as an active character 1328⟩
  else begin p ← new_noad; math_type(nucleus(p)) ← math_char;
    character(nucleus(p)) ← qi(c mod 256); fam(nucleus(p)) ← (c div 256) mod 16;
    if c ≥ var_code then
      begin if fam_in_range then fam(nucleus(p)) ← cur_fam;
        type(p) ← ord_noad;
      end
    else type(p) ← ord_noad + (c div '10000);
      link(tail) ← p; tail ← p;
    end;
  end;

```

1332. Primitive math operators like `\mathop` and `\underline` are given the command code *math_comp*, supplemented by the noad type that they generate.

```

⟨Put each of TeX's primitives into the hash table 244⟩ +≡
primitive("mathord", math_comp, ord_noad); primitive("mathop", math_comp, op_noad);
primitive("mathbin", math_comp, bin_noad); primitive("mathrel", math_comp, rel_noad);
primitive("mathopen", math_comp, open_noad); primitive("mathclose", math_comp, close_noad);
primitive("mathpunct", math_comp, punct_noad); primitive("mathinner", math_comp, inner_noad);
primitive("underline", math_comp, under_noad); primitive("overline", math_comp, over_noad);
primitive("displaylimits", limit_switch, normal); primitive("limits", limit_switch, limits);
primitive("nolimits", limit_switch, no_limits);

```

1333. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
math_comp: case chr_code of
  ord_noad: print_esc("mathord");
  op_noad: print_esc("mathop");
  bin_noad: print_esc("mathbin");
  rel_noad: print_esc("mathrel");
  open_noad: print_esc("mathopen");
  close_noad: print_esc("mathclose");
  punct_noad: print_esc("mathpunct");
  inner_noad: print_esc("mathinner");
  under_noad: print_esc("underline");
  othercases print_esc("overline")
endcases;
limit_switch: if chr_code = limits then print_esc("limits")
else if chr_code = no_limits then print_esc("nolimits")
else print_esc("displaylimits");
```

1334. \langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```
mmode + math_comp: begin tail_append(new_noad); type(tail)  $\leftarrow$  cur_chr; scan_math(nucleus(tail));
end;
mmode + limit_switch: math_limit_switch;
```

1335. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure math_limit_switch;
  label exit;
  begin if head  $\neq$  tail then
    if type(tail) = op_noad then
      begin subtype(tail)  $\leftarrow$  cur_chr; return;
    end;
    print_err("Limit_controls_must_follow_a_math_operator");
    help1("I'm_ignoring_this_misplaced_\limits_or_\nolimits_command."); error;
  exit: end;
```

1336. Delimiter fields of noads are filled in by the *scan_delimiter* routine. The first parameter of this procedure is the *mem* address where the delimiter is to be placed; the second tells if this delimiter follows \backslash radical or not.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure scan_delimiter(p : pointer; r : boolean);
  begin if r then scan_twenty_seven_bit_int
else begin  $\langle$  Get the next non-blank non-relax non-call token 430  $\rangle$ ;
    case cur_cmd of
      letter, other_char: cur_val  $\leftarrow$  del_code(cur_chr);
      delim_num: scan_twenty_seven_bit_int;
    othercases cur_val  $\leftarrow$  -1
    endcases;
    end;
  if cur_val < 0 then
     $\langle$  Report that an invalid delimiter code is being changed to null; set cur_val  $\leftarrow$  0 1337  $\rangle$ ;
    small_fam(p)  $\leftarrow$  (cur_val div '4000000) mod 16; small_char(p)  $\leftarrow$  qi((cur_val div '10000) mod 256);
    large_fam(p)  $\leftarrow$  (cur_val div 256) mod 16; large_char(p)  $\leftarrow$  qi(cur_val mod 256);
  end;
```

1337. \langle Report that an invalid delimiter code is being changed to null; set $cur_val \leftarrow 0$ **1337** $\rangle \equiv$

```

begin print_err("Missing_delimiter_(.inserted)");
help6("I_was expecting to see something like `(` or `{ or `\"")
("`\" here. If you typed, e.g., `{ instead of `{\", you")
("should probably delete the `{ by typing `1 now, so that")
("braces don't get unbalanced. Otherwise just proceed.")
("Acceptable delimiters are characters whose \delcode is")
("nonnegative, or you can use `delimiter<delimiter code>`"); back_error; cur_val ← 0;
end

```

This code is used in section [1336](#).

1338. \langle Cases of *main_control* that build boxes and lists [1232](#) $\rangle + \equiv$
 $mmode + radical$: *math_radical*;

1339. \langle Declare action procedures for use by *main_control* [1219](#) $\rangle + \equiv$
procedure *math_radical*;
begin *tail_append*(*get_node*(*radical_noad_size*)); *type*(*tail*) \leftarrow *radical_noad*; *subtype*(*tail*) \leftarrow *normal*;
mem[*nucleus*(*tail*)].*hh* \leftarrow *empty_field*; *mem*[*subscr*(*tail*)].*hh* \leftarrow *empty_field*;
mem[*supscr*(*tail*)].*hh* \leftarrow *empty_field*; *scan_delimiter*(*left_delimiter*(*tail*), *true*); *scan_math*(*nucleus*(*tail*));
end;

1340. \langle Cases of *main_control* that build boxes and lists [1232](#) $\rangle + \equiv$
 $mmode + accent$, $mmode + math_accent$: *math_ac*;

1341. \langle Declare action procedures for use by *main_control* [1219](#) $\rangle + \equiv$
procedure *math_ac*;
begin if *cur_cmd* = *accent* **then** \langle Complain that the user should have said *\mathaccent* [1342](#) \rangle ;
tail_append(*get_node*(*accent_noad_size*)); *type*(*tail*) \leftarrow *accent_noad*; *subtype*(*tail*) \leftarrow *normal*;
mem[*nucleus*(*tail*)].*hh* \leftarrow *empty_field*; *mem*[*subscr*(*tail*)].*hh* \leftarrow *empty_field*;
mem[*supscr*(*tail*)].*hh* \leftarrow *empty_field*; *math_type*(*accent_chr*(*tail*)) \leftarrow *math_char*; *scan_fifteen_bit_int*;
character(*accent_chr*(*tail*)) \leftarrow *qi*(*cur_val mod* 256);
if (*cur_val* \geq *var_code*) \wedge *fam_in_range* **then** *fam*(*accent_chr*(*tail*)) \leftarrow *cur_fam*
else *fam*(*accent_chr*(*tail*)) \leftarrow (*cur_val div* 256) *mod* 16;
scan_math(*nucleus*(*tail*));
end;

1342. \langle Complain that the user should have said *\mathaccent* [1342](#) $\rangle \equiv$
begin *print_err*("Please use"); *print_esc*("mathaccent"); *print*("for accents in math mode");
help2("I'm changing accent to \mathaccent here; wish me luck.")
(" (Accents are not the same in formulas as they are in text.)"); *error*;
end

This code is used in section [1341](#).

1343. \langle Cases of *main_control* that build boxes and lists [1232](#) $\rangle + \equiv$
 $mmode + vcenter$: **begin** *scan_spec*(*vcenter_group*, *false*); *normal_paragraph*; *push_nest*; *mode* \leftarrow $-vmode$;
prev_depth \leftarrow *pdf_ignored_dimen*;
if *every_vbox* \neq *null* **then** *begin_token_list*(*every_vbox*, *every_vbox_text*);
end;

1344. \langle Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261 $\rangle + \equiv$
vcenter_group: **begin** *end_graf*; *unsave*; *save_ptr* \leftarrow *save_ptr* - 2;
 p \leftarrow *vpack*(*link*(*head*), *saved*(1), *saved*(0)); *pop_nest*; *tail_append*(*new_noad*); *type*(*tail*) \leftarrow *vcenter_noad*;
 math_type(*nucleus*(*tail*)) \leftarrow *sub_box*; *info*(*nucleus*(*tail*)) \leftarrow *p*;
end;

1345. The routine that inserts a *style_node* holds no surprises.

\langle Put each of \TeX 's primitives into the hash table 244 $\rangle + \equiv$
 primitive("displaystyle", *math_style*, *display_style*); *primitive*("textstyle", *math_style*, *text_style*);
 primitive("scriptstyle", *math_style*, *script_style*);
 primitive("scriptscriptstyle", *math_style*, *script_script_style*);

1346. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
math_style: *print_style*(*chr_code*);

1347. \langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$
mmode + *math_style*: *tail_append*(*new_style*(*cur_chr*));
mmode + *non_script*: **begin** *tail_append*(*new_glue*(*zero_glue*)); *subtype*(*tail*) \leftarrow *cond_math_glue*;
end;
mmode + *math_choice*: *append_choices*;

1348. The routine that scans the four mlists of a $\backslash\text{mathchoice}$ is very much like the routine that builds discretionary nodes.

\langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
procedure *append_choices*;
 begin *tail_append*(*new_choice*); *incr*(*save_ptr*); *saved*(-1) \leftarrow 0; *push_math*(*math_choice_group*);
 scan_left_brace;
end;

1349. \langle Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261 $\rangle + \equiv$
math_choice_group: *build_choices*;

1350. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
 \langle Declare the function called *fin_mlist* 1360 \rangle
procedure *build_choices*;

label *exit*;
 var *p*: *pointer*; { the current mlist }
 begin *unsave*; *p* \leftarrow *fin_mlist*(*null*);
 case *saved*(-1) **of**
 0: *display_mlist*(*tail*) \leftarrow *p*;
 1: *text_mlist*(*tail*) \leftarrow *p*;
 2: *script_mlist*(*tail*) \leftarrow *p*;
 3: **begin** *script_script_mlist*(*tail*) \leftarrow *p*; *decr*(*save_ptr*); **return**;
 end;
 end; { there are no other cases }
 incr(*saved*(-1)); *push_math*(*math_choice_group*); *scan_left_brace*;
exit: **end**;

1351. Subscripts and superscripts are attached to the previous nucleus by the action procedure called *sub_sup*. We use the facts that $sub_mark = sup_mark + 1$ and $subscr(p) = supscr(p) + 1$.

⟨Cases of *main_control* that build boxes and lists 1232⟩ +≡
 $mmode + sub_mark, mmode + sup_mark: sub_sup;$

1352. ⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```

procedure sub_sup;
  var t: small_number; { type of previous sub/superscript }
    p: pointer; { field to be filled by scan_math }
  begin t ← empty; p ← null;
  if tail ≠ head then
    if scripts_allowed(tail) then
      begin p ← supscr(tail) + cur_cmd − sup_mark; { supscr or subscr }
        t ← math_type(p);
      end;
  if (p = null) ∨ (t ≠ empty) then ⟨Insert a dummy noad to be sub/superscripted 1353⟩;
  scan_math(p);
end;

```

1353. ⟨Insert a dummy noad to be sub/superscripted 1353⟩ ≡

```

begin tail_append(new_noad); p ← supscr(tail) + cur_cmd − sup_mark; { supscr or subscr }
if t ≠ empty then
  begin if cur_cmd = sup_mark then
    begin print_err("Double␣superscript");
      help1("I␣treat␣`x1^2␣essentially␣like␣`x1}{^2.");
    end
  else begin print_err("Double␣subscript");
    help1("I␣treat␣`x1_2␣essentially␣like␣`x1}{_2.");
  end;
  error;
end;
end

```

This code is used in section 1352.

1354. An operation like ‘*\over*’ causes the current mlist to go into a state of suspended animation: *incompleat_noad* points to a *fraction_noad* that contains the mlist-so-far as its numerator, while the denominator is yet to come. Finally when the mlist is finished, the denominator will go into the incompleat fraction noad, and that noad will become the whole formula, unless it is surrounded by ‘*\left*’ and ‘*\right*’ delimiters.

```

define above_code = 0 { ‘\above’ }
define over_code = 1 { ‘\over’ }
define atop_code = 2 { ‘\atop’ }
define delimited_code = 3 { ‘\abovewithdelims’, etc. }

```

⟨Put each of TeX’s primitives into the hash table 244⟩ +≡

```

primitive("above", above, above_code);
primitive("over", above, over_code);
primitive("atop", above, atop_code);
primitive("abovewithdelims", above, delimited_code + above_code);
primitive("overwithdelims", above, delimited_code + over_code);
primitive("atopwithdelims", above, delimited_code + atop_code);

```

1355. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
above: case chr_code of
  over_code: print_esc("over");
  atop_code: print_esc("atop");
  delimited_code + above_code: print_esc("abovewithdelims");
  delimited_code + over_code: print_esc("overwithdelims");
  delimited_code + atop_code: print_esc("atopwithdelims");
othercases print_esc("above")
endcases;
```

1356. \langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

mmode + *above*: *math_fraction*;

1357. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure math_fraction;
  var c: small_number; { the type of generalized fraction we are scanning }
  begin c  $\leftarrow$  cur_chr;
  if incompleat_noad  $\neq$  null then
     $\langle$  Ignore the fraction operation and complain about this ambiguous case 1359  $\rangle$ 
  else begin incompleat_noad  $\leftarrow$  get_node(fraction_noad_size); type(incompleat_noad)  $\leftarrow$  fraction_noad;
    subtype(incompleat_noad)  $\leftarrow$  normal; math_type(numerator(incompleat_noad))  $\leftarrow$  sub_mlist;
    info(numerator(incompleat_noad))  $\leftarrow$  link(head);
    mem[denominator(incompleat_noad)].hh  $\leftarrow$  empty_field;
    mem[left_delimiter(incompleat_noad)].qqqq  $\leftarrow$  null_delimiter;
    mem[right_delimiter(incompleat_noad)].qqqq  $\leftarrow$  null_delimiter;
    link(head)  $\leftarrow$  null; tail  $\leftarrow$  head;  $\langle$  Use code c to distinguish between generalized fractions 1358  $\rangle$ ;
  end;
end;
```

1358. \langle Use code c to distinguish between generalized fractions 1358 $\rangle \equiv$

```
if c  $\geq$  delimited_code then
  begin scan_delimiter(left_delimiter(incompleat_noad), false);
  scan_delimiter(right_delimiter(incompleat_noad), false);
  end;
case c mod delimited_code of
  above_code: begin scan_normal_dimen; thickness(incompleat_noad)  $\leftarrow$  cur_val;
  end;
  over_code: thickness(incompleat_noad)  $\leftarrow$  default_code;
  atop_code: thickness(incompleat_noad)  $\leftarrow$  0;
  end { there are no other cases }
```

This code is used in section 1357.

1359. \langle Ignore the fraction operation and complain about this ambiguous case [1359](#) $\rangle \equiv$

```

begin if  $c \geq delimited\_code$  then
  begin  $scan\_delimiter(garbage, false); scan\_delimiter(garbage, false);$ 
  end;
if  $c \bmod delimited\_code = above\_code$  then  $scan\_normal\_dimen;$ 
 $print\_err("Ambiguous; \_you\_need\_another\_{\_and\_}");$ 
 $help3("I\'m\_ignoring\_this\_fraction\_specification,\_since\_I\_don\'t")$ 
 $("know\_whether\_a\_construction\_like\_`x\_\\over\_y\_\\over\_z\'")$ 
 $("means\_`{x\_\\over\_y}\_\\over\_z\'\_or\_`x\_\\over\_y\_\\over\_z\'"); error;$ 
end

```

This code is used in section [1357](#).

1360. At the end of a math formula or subformula, the *fin_mlist* routine is called upon to return a pointer to the newly completed mlist, and to pop the nest back to the enclosing semantic level. The parameter to *fin_mlist*, if not null, points to a *right_noad* that ends the current mlist; this *right_noad* has not yet been appended.

\langle Declare the function called *fin_mlist* [1360](#) $\rangle \equiv$

```

function  $fin\_mlist(p : pointer) : pointer;$ 
  var  $q : pointer;$  { the mlist to return }
  begin if  $incomplete\_noad \neq null$  then  $\langle$  Compleat the incomplete noad 1361  $\rangle$ 
  else begin  $link(tail) \leftarrow p; q \leftarrow link(head);$ 
    end;
   $pop\_nest; fin\_mlist \leftarrow q;$ 
  end;

```

This code is used in section [1350](#).

1361. \langle Compleat the incomplete noad [1361](#) $\rangle \equiv$

```

begin  $math\_type(denominator(incomplete\_noad)) \leftarrow sub\_mlist;$ 
 $info(denominator(incomplete\_noad)) \leftarrow link(head);$ 
if  $p = null$  then  $q \leftarrow incomplete\_noad$ 
else begin  $q \leftarrow info(numerator(incomplete\_noad));$ 
  if  $(type(q) \neq left\_noad) \vee (delim\_ptr = null)$  then  $confusion("right");$ 
   $info(numerator(incomplete\_noad)) \leftarrow link(delim\_ptr); link(delim\_ptr) \leftarrow incomplete\_noad;$ 
   $link(incomplete\_noad) \leftarrow p;$ 
  end;
end

```

This code is used in section [1360](#).

1362. Now at last we're ready to see what happens when a right brace occurs in a math formula. Two special cases are simplified here: Braces are effectively removed when they surround a single Ord without sub/superscripts, or when they surround an accent that is the nucleus of an Ord atom.

```

⟨ Cases of handle_right_brace where a right_brace triggers a delayed action 1261 ⟩ +≡
: begin unsave; decr(save_ptr);
(saved(0))  $\leftarrow$  sub_mlist; p  $\leftarrow$  fin_mlist(null); info(saved(0))  $\leftarrow$  p;
if p  $\neq$  null then
  if link(p) = null then
    if type(p) = ord_noad then
      begin if math_type(subscr(p)) = empty then
        if math_type(supscr(p)) = empty then
          begin mem[saved(0)].hh  $\leftarrow$  mem[nucleus(p)].hh; free_node(p, noad_size);
          end;
        end
      else if type(p) = accent_noad then
        if saved(0) = nucleus(tail) then
          if type(tail) = ord_noad then ⟨ Replace the tail of the list by p 1363 ⟩;
        end
      end
    end
  end
end;

```

```

1363. ⟨ Replace the tail of the list by p 1363 ⟩  $\equiv$ 
begin q  $\leftarrow$  head;
while link(q)  $\neq$  tail do q  $\leftarrow$  link(q);
link(q)  $\leftarrow$  p; free_node(tail, noad_size); tail  $\leftarrow$  p;
end

```

This code is used in section 1362.

1364. We have dealt with all constructions of math mode except ‘\left’ and ‘\right’, so the picture is completed by the following sections of the program.

```

⟨ Put each of TEX's primitives into the hash table 244 ⟩ +≡
("left", left_right, left_noad); ("right", left_right, right_noad);
(frozen_right)  $\leftarrow$  "right"; eqtb[frozen_right]  $\leftarrow$  eqtb[cur_val];

```

```

1365. ⟨ Cases of print_cmd_chr for symbolic printing of primitives 245 ⟩ +≡
: if chr_code = left_noad then ("left")
  ⟨ Cases of left_right for print_cmd_chr 1695 ⟩
else ("right");

```

```

1366. ⟨ Cases of main_control that build boxes and lists 1232 ⟩ +≡
 + : ;

```


1367. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```

procedure math_left_right;
  var t: small_number; { left_noad or right_noad }
      p: pointer; { new noad }
      q: pointer; { resulting mlist }
  begin t  $\leftarrow$  cur_chr;
  if (t  $\neq$  left_noad)  $\wedge$  (cur_group  $\neq$  math_left_group) then  $\langle$  Try to recover from mismatched \right 1368  $\rangle$ 
  else begin p  $\leftarrow$  new_noad; type(p)  $\leftarrow$  t; scan_delimiter(delimiter(p), false);
    if t = middle_noad then
      begin type(p)  $\leftarrow$  right_noad; subtype(p)  $\leftarrow$  middle_noad;
      end;
    if t = left_noad then q  $\leftarrow$  p
    else begin q  $\leftarrow$  fin_mlist(p); unsave; { end of math_left_group }
      end;
    if t  $\neq$  right_noad then
      begin push_math(math_left_group); link(head)  $\leftarrow$  q; tail  $\leftarrow$  p; delim_ptr  $\leftarrow$  p;
      end
    else begin tail_append(new_noad); type(tail)  $\leftarrow$  inner_noad; math_type(nucleus(tail))  $\leftarrow$  sub_mlist;
      info(nucleus(tail))  $\leftarrow$  q;
      end;
    end;
  end;
end;

```

1368. \langle Try to recover from mismatched \right 1368 $\rangle \equiv$

```

begin if cur_group = math_shift_group then
  begin scan_delimiter(garbage, false); print_err("Extra_");
  if t = middle_noad then
    begin print_esc("middle"); help1("I'm ignoring a middle that had no matching \left.");
    end
  else begin print_esc("right"); help1("I'm ignoring a right that had no matching \left.");
    end;
  error;
  end
else off_save;
end

```

This code is used in section 1367.

1369. Here is the only way out of math mode.

\langle Cases of *main_control* that build boxes and lists 1232 $\rangle + \equiv$

```

mmode + math_shift: if cur_group = math_shift_group then after_math
  else off_save;

```

1370. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
 \langle Declare subprocedures for *after_math* 1741 \rangle

procedure *after_math*;

var *l*: boolean; { ‘\leqno’ instead of ‘\eqno’ }

danger: boolean; { not enough symbol fonts are present }

m: integer; { *m*mode or $-m$ mode }

p: pointer; { the formula }

a: pointer; { box containing equation number }

\langle Local variables for finishing a displayed formula 1374 \rangle

begin *danger* \leftarrow false; \langle Retrieve the prototype box 1739 \rangle ;

\langle Check that the necessary fonts for math symbols are present; if not, flush the current math lists and set
danger \leftarrow true 1371 \rangle ;

m \leftarrow mode; *l* \leftarrow false; *p* \leftarrow *fin_mlist*(null); { this pops the nest }

if mode = $-m$ **then** { end of equation number }

begin \langle Check that another \$ follows 1373 \rangle ;

cur_mlist \leftarrow *p*; *cur_style* \leftarrow *text_style*; *mlist_penalties* \leftarrow false; *mlist_to_hlist*;

a \leftarrow *hpack*(*link*(*temp_head*), *natural*); *set_box_lr*(*a*)(*dlist*); *unsave*; *decr*(*save_ptr*);

{ now *cur_group* = *math_shift_group* }

if *saved*(0) = 1 **then** *l* \leftarrow true;

danger \leftarrow false; \langle Retrieve the prototype box 1739 \rangle ;

\langle Check that the necessary fonts for math symbols are present; if not, flush the current math lists and
set *danger* \leftarrow true 1371 \rangle ;

m \leftarrow mode; *p* \leftarrow *fin_mlist*(null);

end

else *a* \leftarrow null;

if *m* < 0 **then** \langle Finish math in text 1372 \rangle

else begin if *a* = null **then** \langle Check that another \$ follows 1373 \rangle ;

\langle Finish displayed math 1375 \rangle ;

end;

end;

1371. \langle Check that the necessary fonts for math symbols are present; if not, flush the current math lists
and set *danger* \leftarrow true 1371 $\rangle \equiv$

if (*font_params*[*fam_fnt*(2 + *text_size*)] < *total_mathsy_params*) \vee

(*font_params*[*fam_fnt*(2 + *script_size*)] < *total_mathsy_params*) \vee

(*font_params*[*fam_fnt*(2 + *script_script_size*)] < *total_mathsy_params*) **then**

begin *print_err*("Math_formula_deleted: Insufficient_symbol_fonts");

help3("Sorry, but I can't typeset math unless \textfont 2")

("and \scriptfont 2 and \scriptscriptfont 2 have all")

("the \fontdimen values needed in math symbol fonts."); *error*; *flush_math*; *danger* \leftarrow true;

end

else if (*font_params*[*fam_fnt*(3 + *text_size*)] < *total_mathex_params*) \vee

(*font_params*[*fam_fnt*(3 + *script_size*)] < *total_mathex_params*) \vee

(*font_params*[*fam_fnt*(3 + *script_script_size*)] < *total_mathex_params*) **then**

begin *print_err*("Math_formula_deleted: Insufficient_extension_fonts");

help3("Sorry, but I can't typeset math unless \textfont 3")

("and \scriptfont 3 and \scriptscriptfont 3 have all")

("the \fontdimen values needed in math extension fonts."); *error*; *flush_math*;

danger \leftarrow true;

end

This code is used in sections 1370 and 1370.

1372. The *unsave* is done after everything else here; hence an appearance of ‘`\mathsurround`’ inside of ‘`$. . $`’ affects the spacing at these particular ‘`$`’s. This is consistent with the conventions of ‘`$$. . $$`’, since ‘`\abovedisplayskip`’ inside a display affects the space above that display.

```

⟨Finish math in text 1372⟩ ≡
  begin tail_append(new_math(math_surround, before)); cur_mlist ← p; cur_style ← text_style;
  mlist_penalties ← (mode > 0); mlist_to_hlist; link(tail) ← link(temp_head);
  while link(tail) ≠ null do tail ← link(tail);
  tail_append(new_math(math_surround, after)); space_factor ← 1000; unsave;
end

```

This code is used in section 1370.

1373. TeX gets to the following part of the program when the first ‘`$`’ ending a display has been scanned.

```

⟨Check that another $ follows 1373⟩ ≡
  begin get_x_token;
  if cur_cmd ≠ math_shift then
    begin print_err("Display_math_should_end_with_$$");
    help2("The `\$` that I just saw supposedly matches a previous `\$`.")
    ("So I shall assume that you typed `$$$` both times."); back_error;
  end;
end

```

This code is used in sections 1370, 1370, and 1382.

1374. We have saved the worst for last: The fussiest part of math mode processing occurs when a displayed formula is being centered and placed with an optional equation number.

```

⟨Local variables for finishing a displayed formula 1374⟩ ≡
b: pointer; { box containing the equation }
w: scaled; { width of the equation }
z: scaled; { width of the line }
e: scaled; { width of equation number }
q: scaled; { width of equation number plus space to separate from equation }
d: scaled; { displacement of equation in the line }
s: scaled; { move the line right this much }
g1, g2: small_number; { glue parameter codes for before and after }
r: pointer; { kern node used to position the display }
t: pointer; { tail of adjustment list }
pre_t: pointer; { tail of pre-adjustment list }

```

See also section 1738.

This code is used in section 1370.

1375. At this time p points to the mlist for the formula; a is either *null* or it points to a box containing the equation number; and we are in vertical mode (or internal vertical mode).

```

⟨Finish displayed math 1375⟩ ≡
  cur_mlist ← p; cur_style ← display_style; mlist_penalties ← false; mlist_to_hlist; p ← link(temp_head);
  adjust_tail ← adjust_head; pre_adjust_tail ← pre_adjust_head; b ← hpack(p, natural); p ← list_ptr(b);
  t ← adjust_tail; adjust_tail ← null;
  pre_t ← pre_adjust_tail; pre_adjust_tail ← null;
  w ← width(b); z ← display_width; s ← display_indent;
  if pre_display_direction < 0 then s ← -s - z;
  if (a = null) ∨ danger then
    begin e ← 0; q ← 0;
    end
  else begin e ← width(a); q ← e + math_quad(text_size);
    end;
  if w + q > z then ⟨Squeeze the equation as much as possible; if there is an equation number that should
    go on a separate line by itself, set e ← 0 1377⟩;
  ⟨Determine the displacement, d, of the left edge of the equation, with respect to the line size z, assuming
    that l = false 1378⟩;
  ⟨Append the glue or equation number preceding the display 1379⟩;
  ⟨Append the display and perhaps also the equation number 1380⟩;
  ⟨Append the glue or equation number following the display 1381⟩;
  ⟨Flush the prototype box 1740⟩;
  resume_after_display

```

This code is used in section 1370.

1376. ⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```

procedure resume_after_display;
  begin if cur_group ≠ math_shift_group then confusion("display");
  unsave; prev_graf ← prev_graf + 3; push_nest; mode ← hmode; space_factor ← 1000; set_cur_lang;
  clang ← cur_lang;
  prev_graf ← (norm_min(left_hyphen_min) * '100 + norm_min(right_hyphen_min)) * '200000 + cur_lang;
  ⟨Scan an optional space 469⟩;
  if nest_ptr = 1 then build_page;
  end;

```

1377. The user can force the equation number to go on a separate line by causing its width to be zero.

```

⟨Squeeze the equation as much as possible; if there is an equation number that should go on a separate line
  by itself, set e ← 0 1377⟩ ≡
  begin if (e ≠ 0) ∧ ((w - total_shrink[normal] + q ≤ z) ∨
    (total_shrink[fil] ≠ 0) ∨ (total_shrink[fill] ≠ 0) ∨ (total_shrink[filll] ≠ 0)) then
    begin free_node(b, box_node_size); b ← hpack(p, z - q, exactly);
    end
  else begin e ← 0;
    if w > z then
      begin free_node(b, box_node_size); b ← hpack(p, z, exactly);
      end;
    end;
  w ← width(b);
  end

```

This code is used in section 1375.

1378. We try first to center the display without regard to the existence of the equation number. If that would make it too close (where “too close” means that the space between display and equation number is less than the width of the equation number), we either center it in the remaining space or move it as far from the equation number as possible. The latter alternative is taken only if the display begins with glue, since we assume that the user put glue there to control the spacing precisely.

```

⟨ Determine the displacement,  $d$ , of the left edge of the equation, with respect to the line size  $z$ , assuming
  that  $l = \text{false}$  1378 ⟩  $\equiv$ 
   $\text{set\_box\_lr}(b)(dlist)$ ;  $d \leftarrow \text{half}(z - w)$ ;
  if  $(e > 0) \wedge (d < 2 * e)$  then { too close }
    begin  $d \leftarrow \text{half}(z - w - e)$ ;
    if  $p \neq \text{null}$  then
      if  $\neg \text{is\_char\_node}(p)$  then
        if  $\text{type}(p) = \text{glue\_node}$  then  $d \leftarrow 0$ ;
      end
    end

```

This code is used in section 1375.

1379. If the equation number is set on a line by itself, either before or after the formula, we append an infinite penalty so that no page break will separate the display from its number; and we use the same size and displacement for all three potential lines of the display, even though ‘\parshape’ may specify them differently.

```

⟨ Append the glue or equation number preceding the display 1379 ⟩  $\equiv$ 
   $\text{tail\_append}(\text{new\_penalty}(\text{pre\_display\_penalty}))$ ;
  if  $(d + s \leq \text{pre\_display\_size}) \vee l$  then { not enough clearance }
    begin  $g1 \leftarrow \text{above\_display\_skip\_code}$ ;  $g2 \leftarrow \text{below\_display\_skip\_code}$ ;
    end
  else begin  $g1 \leftarrow \text{above\_display\_short\_skip\_code}$ ;  $g2 \leftarrow \text{below\_display\_short\_skip\_code}$ ;
    end;
  if  $l \wedge (e = 0)$  then { it follows that  $\text{type}(a) = \text{hlist\_node}$  }
    begin  $\text{app\_display}(j, a, 0)$ ;  $\text{tail\_append}(\text{new\_penalty}(\text{inf\_penalty}))$ ;
    end
  else  $\text{tail\_append}(\text{new\_param\_glue}(g1))$ 

```

This code is used in section 1375.

```

1380. ⟨ Append the display and perhaps also the equation number 1380 ⟩  $\equiv$ 
  if  $e \neq 0$  then
    begin  $r \leftarrow \text{new\_kern}(z - w - e - d)$ ;
    if  $l$  then
      begin  $\text{link}(a) \leftarrow r$ ;  $\text{link}(r) \leftarrow b$ ;  $b \leftarrow a$ ;  $d \leftarrow 0$ ;
      end
    else begin  $\text{link}(b) \leftarrow r$ ;  $\text{link}(r) \leftarrow a$ ;
      end;
     $b \leftarrow \text{hpack}(b, \text{natural})$ ;
    end;
   $\text{app\_display}(j, b, d)$ 

```

This code is used in section 1375.

1381. \langle Append the glue or equation number following the display 1381 $\rangle \equiv$

```

if ( $a \neq \text{null}$ )  $\wedge$  ( $e = 0$ )  $\wedge$   $\neg l$  then
  begin tail_append(new_penalty(inf_penalty)); app_display( $j, a, z - \text{width}(a)$ );  $g2 \leftarrow 0$ ;
  end;
if  $t \neq \text{adjust\_head}$  then { migrating material comes after equation number }
  begin link(tail)  $\leftarrow$  link(adjust_head); tail  $\leftarrow t$ ;
  end;
if  $\text{pre\_}t \neq \text{pre\_adjust\_head}$  then
  begin link(tail)  $\leftarrow$  link(pre_adjust_head); tail  $\leftarrow \text{pre\_}t$ ;
  end;
tail_append(new_penalty(post_display_penalty));
if  $g2 > 0$  then tail_append(new_param_glue( $g2$ ))

```

This code is used in section 1375.

1382. When `\halign` appears in a display, the alignment routines operate essentially as they do in vertical mode. Then the following program is activated, with p and q pointing to the beginning and end of the resulting list, and with *aux_save* holding the *prev_depth* value.

\langle Finish an alignment in a display 1382 $\rangle \equiv$

```

begin do_assignments;
if cur_cmd  $\neq$  math_shift then  $\langle$  Pontificate about improper alignment in display 1383  $\rangle$ 
else  $\langle$  Check that another $ follows 1373  $\rangle$ ;
flush_node_list(LR_box); pop_nest; tail_append(new_penalty(pre_display_penalty));
tail_append(new_param_glue(above_display_skip_code)); link(tail)  $\leftarrow p$ ;
if  $p \neq \text{null}$  then tail  $\leftarrow q$ ;
tail_append(new_penalty(post_display_penalty)); tail_append(new_param_glue(below_display_skip_code));
prev_depth  $\leftarrow$  aux_save.sc; resume_after_display;
end

```

This code is used in section 986.

1383. \langle Pontificate about improper alignment in display 1383 $\rangle \equiv$

```

begin print_err("Missing_$$_inserted");
help2("Displays_can_use_special_alignments_(like_\eqalignno)")
("only_if_nothing_but_the_alignment_itself_is_between_$$'s."); back_error;
end

```

This code is used in section 1382.

1384. Mode-independent processing. The long *main_control* procedure has now been fully specified, except for certain activities that are independent of the current mode. These activities do not change the current vlist or hlist; if they change anything, it is the value of a parameter or the meaning of a control sequence.

Assignments to values in *eqtb* can be global or local. Furthermore, a control sequence can be defined to be ‘\long’, ‘\protected’, or ‘\outer’, and it might or might not be expanded. The prefixes ‘\global’, ‘\long’, ‘\protected’, and ‘\outer’ can occur in any order. Therefore we assign binary numeric codes, making it possible to accumulate the union of all specified prefixes by adding the corresponding codes. (Pascal’s *set* operations could also have been used.)

```
⟨ Put each of TEX’s primitives into the hash table 244 ⟩ +=
  primitive("long", prefix, 1); primitive("outer", prefix, 2); primitive("global", prefix, 4);
  primitive("def", def, 0); primitive("gdef", def, 1); primitive("edef", def, 2); primitive("xdef", def, 3);
```

1385. ⟨ Cases of *print_cmd_chr* for symbolic printing of primitives 245 ⟩ +=

```
prefix: if chr_code = 1 then print_esc("long")
      else if chr_code = 2 then print_esc("outer")
⟨ Cases of prefix for print_cmd_chr 1768 ⟩
else print_esc("global");
def: if chr_code = 0 then print_esc("def")
    else if chr_code = 1 then print_esc("gdef")
    else if chr_code = 2 then print_esc("edef")
    else print_esc("xdef");
```

1386. Every prefix, and every command code that might or might not be prefixed, calls the action procedure *prefixed_command*. This routine accumulates a sequence of prefixes until coming to a non-prefix, then it carries out the command.

⟨ Cases of *main_control* that don’t depend on mode 1386 ⟩ ≡

```
any_mode(toks_register), any_mode(assign_toks), any_mode(assign_int), any_mode(assign_dimen),
  any_mode(assign_glue), any_mode(assign_mu_glue), any_mode(assign_font_dimen),
  any_mode(assign_font_int), any_mode(set_aux), any_mode(set_prev_graf), any_mode(set_page_dimen),
  any_mode(set_page_int), any_mode(set_box_dimen), any_mode(set_shape), any_mode(def_code),
  any_mode(def_family), any_mode(set_font), any_mode(def_font), any_mode(letterspace_font),
  any_mode(pdf_copy_font), any_mode(register), any_mode(advance), any_mode(multiply),
  any_mode(divide), any_mode(prefix), any_mode(let), any_mode(shorthand_def), any_mode(read_to_cs),
  any_mode(def), any_mode(set_box), any_mode(hyph_data), any_mode(set_interaction):
  prefixed_command;
```

See also sections 1444, 1447, 1450, 1452, 1461, and 1466.

This code is used in section 1221.

1387. If the user says, e.g., ‘\global\global’, the redundancy is silently accepted.

⟨ Declare action procedures for use by *main_control* 1219 ⟩ +≡

⟨ Declare subprocedures for *prefixed_command* 1391 ⟩

procedure *prefixed_command*;

label *done, exit*;

var *a*: *small_number*; { accumulated prefix codes so far }

f: *internal_font_number*; { identifies a font }

j: *halfword*; { index into a \parshape specification }

k: *font_index*; { index into *font_info* }

p, q: *pointer*; { for temporary short-term use }

n: *integer*; { ditto }

e: *boolean*; { should a definition be expanded? or was \let not done? }

begin *a* ← 0;

while *cur_cmd* = *prefix* **do**

begin if ¬*odd*(*a* div *cur_chr*) **then** *a* ← *a* + *cur_chr*;

 ⟨ Get the next non-blank non-relax non-call token 430 ⟩;

if *cur_cmd* ≤ *max_non_prefixed_command* **then** ⟨ Discard erroneous prefixes and **return** 1388 ⟩;

if *tracing_commands* > 2 **then**

if *eTeX_ex* **then** *show_cur_cmd_chr*;

end;

 ⟨ Discard the prefixes \long and \outer if they are irrelevant 1389 ⟩;

 ⟨ Adjust for the setting of \globaldefs 1390 ⟩;

case *cur_cmd* **of**

 ⟨ Assignments 1393 ⟩

othercases *confusion*("prefix")

endcases;

done: ⟨ Insert a token saved by \afterassignment, if any 1445 ⟩;

exit: **end**;

1388. ⟨ Discard erroneous prefixes and **return** 1388 ⟩ ≡

begin *print_err*("You can't use a prefix with `"); *print_cmd_chr*(*cur_cmd*, *cur_chr*);

print_char("`"); *help1*("I'll pretend you didn't say \long or \outer or \global.");

if *eTeX_ex* **then**

help_line[0] ← "I'll pretend you didn't say \long or \outer or \global or \protected.";

back_error; **return**;

end

This code is used in section 1387.

1389. \langle Discard the prefixes `\long` and `\outer` if they are irrelevant 1389 $\rangle \equiv$

```

if  $a \geq 8$  then
  begin  $j \leftarrow \textit{protected\_token}$ ;  $a \leftarrow a - 8$ ;
  end
else  $j \leftarrow 0$ ;
if ( $\textit{cur\_cmd} \neq \textit{def}$ )  $\wedge ((a \bmod 4 \neq 0) \vee (j \neq 0))$  then
  begin  $\textit{print\_err}$ ("You can't use ");  $\textit{print\_esc}$ ("long");  $\textit{print}$ (" or ");  $\textit{print\_esc}$ ("outer");
   $\textit{help1}$ ("I'll pretend you didn't say \long or \outer here.");
  if eTeX then
    begin  $\textit{help\_line}[0] \leftarrow$  "I'll pretend you didn't say \long or \outer or \protected here.";
     $\textit{print}$ (" or ");  $\textit{print\_esc}$ ("protected");
    end;
   $\textit{print}$ (" with ");  $\textit{print\_cmd\_chr}(\textit{cur\_cmd}, \textit{cur\_chr})$ ;  $\textit{print\_char}$ (" "); error;
  end

```

This code is used in section 1387.

1390. The previous routine does not have to adjust a so that $a \bmod 4 = 0$, since the following routines test for the `\global` prefix as follows.

```

define global  $\equiv (a \geq 4)$ 
define define(#)  $\equiv$ 
  if global then geq_define(#) else eq_define(#)
define word_define(#)  $\equiv$ 
  if global then geq_word_define(#) else eq_word_define(#)

```

\langle Adjust for the setting of `\globaldefs` 1390 $\rangle \equiv$

```

if global_defs  $\neq 0$  then
  if global_defs  $< 0$  then
    begin if global then  $a \leftarrow a - 4$ ;
    end
  else begin if  $\neg \textit{global}$  then  $a \leftarrow a + 4$ ;
  end

```

This code is used in section 1387.

1391. When a control sequence is to be defined, by `\def` or `\let` or something similar, the *get_r_token* routine will substitute a special control sequence for a token that is not redefinable.

\langle Declare subprocedures for *prefixed_command* 1391 $\rangle \equiv$

```
procedure get_r_token;
  label restart;
  begin restart: repeat get_token;
  until cur_tok  $\neq$  space_token;
  if (cur_cs = 0)  $\vee$  (cur_cs > frozen_control_sequence) then
    begin print_err("Missing_control_sequence_inserted");
    help5("Please_don't_say_`\def_cs{...}`", say_`\def_cs{...}`".)
    (I've_inserted_an_inaccessible_control_sequence_so_that_your)
    (definition_will_be_completed_without_mixing_me_up_too_badly.)
    (You_can_recover_graciously_from_this_error_if_you're)
    (careful; see exercise 27.2 in The TeXbook.");
    if cur_cs = 0 then back_input;
    cur_tok  $\leftarrow$  cs_token_flag + frozen_protection; ins_error; goto restart;
  end;
end;
```

See also sections 1405, 1412, 1419, 1420, 1421, 1422, 1423, 1433, and 1441.

This code is used in section 1387.

1392. \langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$
text(frozen_protection) \leftarrow "inaccessible";

1393. Here's an example of the way many of the following routines operate. (Unfortunately, they aren't all as simple as this.)

\langle Assignments 1393 $\rangle \equiv$

```
set_font: define(cur_font_loc, data, cur_chr);
```

See also sections 1394, 1397, 1400, 1401, 1402, 1404, 1408, 1410, 1411, 1417, 1418, 1424, 1428, 1429, 1432, and 1440.

This code is used in section 1387.

1394. When a *def* command has been scanned, *cur_chr* is odd if the definition is supposed to be global, and *cur_chr* ≥ 2 if the definition is supposed to be expanded.

\langle Assignments 1393 $\rangle + \equiv$

```
def: begin if odd(cur_chr)  $\wedge$   $\neg$ global  $\wedge$  (global_defs  $\geq$  0) then a  $\leftarrow$  a + 4;
  e  $\leftarrow$  (cur_chr  $\geq$  2); get_r_token; p  $\leftarrow$  cur_cs; q  $\leftarrow$  scan_toks(true, e);
  if j  $\neq$  0 then
    begin q  $\leftarrow$  get_avail; info(q)  $\leftarrow$  j; link(q)  $\leftarrow$  link(def_ref); link(def_ref)  $\leftarrow$  q;
    end;
  define(p, call + (a mod 4), def_ref);
end;
```

1395. Both `\let` and `\futurelet` share the command code *let*.

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```
primitive("let", let, normal);
primitive("futurelet", let, normal + 1);
```

1396. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
let: **if** *chr_code* \neq *normal* **then** *print_esc*("futurelet") **else** *print_esc*("let");

1397. \langle Assignments 1393 $\rangle + \equiv$

```

let: begin  $n \leftarrow cur\_chr$ ;  $get\_r\_token$ ;  $p \leftarrow cur\_cs$ ;
  if  $n = normal$  then
    begin repeat  $get\_token$ ;
    until  $cur\_cmd \neq spacer$ ;
    if  $cur\_tok = other\_token + "="$  then
      begin  $get\_token$ ;
      if  $cur\_cmd = spacer$  then  $get\_token$ ;
      end;
    end
  else begin  $get\_token$ ;  $q \leftarrow cur\_tok$ ;  $get\_token$ ;  $back\_input$ ;  $cur\_tok \leftarrow q$ ;  $back\_input$ ;
    { look ahead, then back up }
  end; { note that  $back\_input$  doesn't affect  $cur\_cmd$ ,  $cur\_chr$  }
if  $cur\_cmd \geq call$  then  $add\_token\_ref(cur\_chr)$ 
else if  $(cur\_cmd = register) \vee (cur\_cmd = toks\_register)$  then
  if  $(cur\_chr < mem\_bot) \vee (cur\_chr > lo\_mem\_stat\_max)$  then  $add\_sa\_ref(cur\_chr)$ ;
   $define(p, cur\_cmd, cur\_chr)$ ;
end;

```

1398. A `\chardef` creates a control sequence whose *cmd* is *char_given*; a `\mathchardef` creates a control sequence whose *cmd* is *math_given*; and the corresponding *chr* is the character code or math code. A `\countdef` or `\dimendef` or `\skipdef` or `\muskipdef` creates a control sequence whose *cmd* is *assign_int* or ... or *assign_mu_glue*, and the corresponding *chr* is the *eqtb* location of the internal register in question.

```

define  $char\_def\_code = 0$  { shorthand_def for \chardef }
define  $math\_char\_def\_code = 1$  { shorthand_def for \mathchardef }
define  $count\_def\_code = 2$  { shorthand_def for \countdef }
define  $dimen\_def\_code = 3$  { shorthand_def for \dimendef }
define  $skip\_def\_code = 4$  { shorthand_def for \skipdef }
define  $mu\_skip\_def\_code = 5$  { shorthand_def for \muskipdef }
define  $toks\_def\_code = 6$  { shorthand_def for \toksdef }

```

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```

primitive("chardef", shorthand_def, char_def_code);
primitive("mathchardef", shorthand_def, math_char_def_code);
primitive("countdef", shorthand_def, count_def_code);
primitive("dimendef", shorthand_def, dimen_def_code);
primitive("skipdef", shorthand_def, skip_def_code);
primitive("muskipdef", shorthand_def, mu_skip_def_code);
primitive("toksdef", shorthand_def, toks_def_code);

```

1399. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
shorthand_def: case chr_code of
  char_def_code: print_esc("chardef");
  math_char_def_code: print_esc("mathchardef");
  count_def_code: print_esc("countdef");
  dimen_def_code: print_esc("dimendef");
  skip_def_code: print_esc("skipdef");
  mu_skip_def_code: print_esc("muskipdef");
  othercases print_esc("toksdef")
endcases;
char_given: begin print_esc("char"); print_hex(chr_code);
end;
math_given: begin print_esc("mathchar"); print_hex(chr_code);
end;
```

1400. We temporarily define *p* to be *relax*, so that an occurrence of *p* while scanning the definition will simply stop the scanning instead of producing an “undefined control sequence” error or expanding the previous meaning. This allows, for instance, ‘\chardef\foo=123\foo’.

\langle Assignments 1393 $\rangle + \equiv$

```
shorthand_def: begin n  $\leftarrow$  cur_chr; get_r_token; p  $\leftarrow$  cur_cs; define(p, relax, 256); scan_optional_equals;
case n of
  char_def_code: begin scan_char_num; define(p, char_given, cur_val);
  end;
  math_char_def_code: begin scan_fifteen_bit_int; define(p, math_given, cur_val);
  end;
  othercases begin scan_register_num;
  if cur_val > 255 then
    begin j  $\leftarrow$  n - count_def_code; { int_val .. box_val }
    if j > mu_val then j  $\leftarrow$  tok_val; { int_val .. mu_val or tok_val }
    find_sa_element(j, cur_val, true); add_sa_ref(cur_ptr);
    if j = tok_val then j  $\leftarrow$  toks_register else j  $\leftarrow$  register;
    define(p, j, cur_ptr);
  end
  else case n of
    count_def_code: define(p, assign_int, count_base + cur_val);
    dimen_def_code: define(p, assign_dimen, scaled_base + cur_val);
    skip_def_code: define(p, assign_glue, skip_base + cur_val);
    mu_skip_def_code: define(p, assign_mu_glue, mu_skip_base + cur_val);
    toks_def_code: define(p, assign_toks, toks_base + cur_val);
  end; { there are no other cases }
  end
endcases;
end;
```

1401. $\langle \text{Assignments 1393} \rangle + \equiv$

```
read_to_cs: begin  $j \leftarrow \text{cur\_chr}$ ;  $\text{scan\_int}$ ;  $n \leftarrow \text{cur\_val}$ ;
  if  $\neg \text{scan\_keyword}(\text{"to"})$  then
    begin  $\text{print\_err}(\text{"Missing\_to\_inserted"})$ ;
       $\text{help2}(\text{"You\_should\_have\_said\_read<number>\_to\_cs\_"})$ 
       $(\text{"I\_m\_going\_to\_look\_for\_the\_cs\_now\_"})$ ;  $\text{error}$ ;
    end;
   $\text{get\_r\_token}$ ;  $p \leftarrow \text{cur\_cs}$ ;  $\text{read\_toks}(n, p, j)$ ;  $\text{define}(p, \text{call}, \text{cur\_val})$ ;
end;
```

1402. The token-list parameters, `\output` and `\everypar`, etc., receive their values in the following way. (For safety's sake, we place an enclosing pair of braces around an `\output` list.)

$\langle \text{Assignments 1393} \rangle + \equiv$

```
toks_register, assign_toks: begin  $q \leftarrow \text{cur\_cs}$ ;  $e \leftarrow \text{false}$ ;
  { just in case, will be set true for sparse array elements }
if  $\text{cur\_cmd} = \text{toks\_register}$  then
  if  $\text{cur\_chr} = \text{mem\_bot}$  then
    begin  $\text{scan\_register\_num}$ ;
      if  $\text{cur\_val} > 255$  then
        begin  $\text{find\_sa\_element}(\text{tok\_val}, \text{cur\_val}, \text{true})$ ;  $\text{cur\_chr} \leftarrow \text{cur\_ptr}$ ;  $e \leftarrow \text{true}$ ;
        end
      else  $\text{cur\_chr} \leftarrow \text{toks\_base} + \text{cur\_val}$ ;
      end
    else  $e \leftarrow \text{true}$ ;
   $p \leftarrow \text{cur\_chr}$ ; {  $p = \text{every\_par\_loc}$  or  $\text{output\_routine\_loc}$  or ... }
   $\text{scan\_optional\_equals}$ ;  $\langle \text{Get the next non-blank non-relax non-call token 430} \rangle$ ;
  if  $\text{cur\_cmd} \neq \text{left\_brace}$  then  $\langle \text{If the right-hand side is a token parameter or token register, finish the}$ 
    assignment and goto done 1403;
   $\text{back\_input}$ ;  $\text{cur\_cs} \leftarrow q$ ;  $q \leftarrow \text{scan\_toks}(\text{false}, \text{false})$ ;
  if  $\text{link}(\text{def\_ref}) = \text{null}$  then { empty list: revert to the default }
    begin  $\text{sa\_define}(p, \text{null})(p, \text{undefined\_cs}, \text{null})$ ;  $\text{free\_avail}(\text{def\_ref})$ ;
    end
  else begin if  $(p = \text{output\_routine\_loc}) \wedge \neg e$  then { enclose in curlyes }
    begin  $\text{link}(q) \leftarrow \text{get\_avail}$ ;  $q \leftarrow \text{link}(q)$ ;  $\text{info}(q) \leftarrow \text{right\_brace\_token} + \text{"}"$ ;  $q \leftarrow \text{get\_avail}$ ;
       $\text{info}(q) \leftarrow \text{left\_brace\_token} + \text{"{"}$ ;  $\text{link}(q) \leftarrow \text{link}(\text{def\_ref})$ ;  $\text{link}(\text{def\_ref}) \leftarrow q$ ;
    end;
     $\text{sa\_define}(p, \text{def\_ref})(p, \text{call}, \text{def\_ref})$ ;
  end;
end;
```

1403. \langle If the right-hand side is a token parameter or token register, finish the assignment and **goto** *done* 1403 $\rangle \equiv$

```

if (cur_cmd = toks_register)  $\vee$  (cur_cmd = assign_toks) then
  begin if cur_cmd = toks_register then
    if cur_chr = mem_bot then
      begin scan_register_num;
      if cur_val < 256 then q  $\leftarrow$  equiv(toks_base + cur_val)
      else begin find_sa_element(tok_val, cur_val, false);
        if cur_ptr = null then q  $\leftarrow$  null
        else q  $\leftarrow$  sa_ptr(cur_ptr);
        end;
      end
      else q  $\leftarrow$  sa_ptr(cur_chr)
    else q  $\leftarrow$  equiv(cur_chr);
    if q = null then sa_define(p, null)(p, undefined_cs, null)
    else begin add_token_ref(q); sa_define(p, q)(p, call, q);
      end;
    goto done;
  end

```

This code is used in section 1402.

1404. Similar routines are used to assign values to the numeric parameters.

```

 $\langle$  Assignments 1393  $\rangle + \equiv$ 
assign_int: begin p  $\leftarrow$  cur_chr; scan_optional_equals; scan_int; word_define(p, cur_val);
  end;
assign_dimen: begin p  $\leftarrow$  cur_chr; scan_optional_equals; scan_normal_dimen; word_define(p, cur_val);
  end;
assign_glue, assign_mu_glue: begin p  $\leftarrow$  cur_chr; n  $\leftarrow$  cur_cmd; scan_optional_equals;
  if n = assign_mu_glue then scan_glue(mu_val) else scan_glue(glue_val);
  trap_zero_glue; define(p, glue_ref, cur_val);
  end;

```

1405. When a glue register or parameter becomes zero, it will always point to *zero_glue* because of the following procedure. (Exception: The tabskip glue isn't trapped while preambles are being scanned.)

```

 $\langle$  Declare subprocedures for prefixed_command 1391  $\rangle + \equiv$ 
procedure trap_zero_glue;
  begin if (width(cur_val) = 0)  $\wedge$  (stretch(cur_val) = 0)  $\wedge$  (shrink(cur_val) = 0) then
    begin add_glue_ref(zero_glue); delete_glue_ref(cur_val); cur_val  $\leftarrow$  zero_glue;
    end;
  end;

```

1406. The various character code tables are changed by the *def_code* commands, and the font families are declared by *def_family*.

```

 $\langle$  Put each of TeX's primitives into the hash table 244  $\rangle + \equiv$ 
primitive("catcode", def_code, cat_code_base); primitive("mathcode", def_code, math_code_base);
primitive("lccode", def_code, lc_code_base); primitive("uccode", def_code, uc_code_base);
primitive("sfcode", def_code, sf_code_base); primitive("delcode", def_code, del_code_base);
primitive("textfont", def_family, math_font_base);
primitive("scriptfont", def_family, math_font_base + script_size);
primitive("scriptscriptfont", def_family, math_font_base + script_script_size);

```

1407. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
def_code: if chr_code = cat_code_base then print_esc("catcode")
  else if chr_code = math_code_base then print_esc("mathcode")
  else if chr_code = lc_code_base then print_esc("lccode")
  else if chr_code = uc_code_base then print_esc("uccode")
  else if chr_code = sf_code_base then print_esc("sfcode")
  else print_esc("delcode");
def_family: print_size(chr_code - math_font_base);
```

1408. The different types of code values have different legal ranges; the following program is careful to check each case properly.

\langle Assignments 1393 $\rangle + \equiv$

```
def_code: begin  $\langle$  Let  $n$  be the largest legal code value, based on cur_chr 1409  $\rangle$ ;
  p  $\leftarrow$  cur_chr; scan_char_num; p  $\leftarrow$  p + cur_val; scan_optional_equals; scan_int;
  if ((cur_val < 0)  $\wedge$  (p < del_code_base))  $\vee$  (cur_val > n) then
    begin print_err("Invalid_code_"); print_int(cur_val);
    if p < del_code_base then print("),_should_be_in_the_range_0..")
    else print("),_should_be_at_most_");
    print_int(n); help1("I'm_going_to_use_0_instead_of_that_illegal_code_value.");
    error; cur_val  $\leftarrow$  0;
  end;
  if p < math_code_base then define(p, data, cur_val)
  else if p < del_code_base then define(p, data, hi(cur_val))
  else word_define(p, cur_val);
end;
```

1409. \langle Let n be the largest legal code value, based on *cur_chr* 1409 $\rangle \equiv$

```
if cur_chr = cat_code_base then n  $\leftarrow$  max_char_code
else if cur_chr = math_code_base then n  $\leftarrow$  '100000
else if cur_chr = sf_code_base then n  $\leftarrow$  '77777
else if cur_chr = del_code_base then n  $\leftarrow$  '77777777
else n  $\leftarrow$  255
```

This code is used in section 1408.

1410. \langle Assignments 1393 $\rangle + \equiv$

```
def_family: begin p  $\leftarrow$  cur_chr; scan_four_bit_int; p  $\leftarrow$  p + cur_val; scan_optional_equals; scan_font_ident;
  define(p, data, cur_val);
end;
```

1411. Next we consider changes to TeX's numeric registers.

\langle Assignments 1393 $\rangle + \equiv$

```
register, advance, multiply, divide: do_register_command(a);
```

1412. We use the fact that $register < advance < multiply < divide$.

⟨ Declare subprocedures for *prefixed_command* 1391 ⟩ +≡

```
procedure do_register_command(a : small_number);
  label found, exit;
  var l, q, r, s: pointer; { for list manipulation }
      p: int_val .. mu_val; { type of register involved }
      e: boolean; { does l refer to a sparse array element? }
      w: integer; { integer or dimen value of l }
  begin q ← cur_cmd; e ← false; { just in case, will be set true for sparse array elements }
  ⟨ Compute the register location l and its type p; but return if invalid 1413 ⟩;
  if q = register then scan_optional_equals
  else if scan_keyword("by") then do_nothing; { optional 'by' }
  arith_error ← false;
  if q < multiply then ⟨ Compute result of register or advance, put it in cur_val 1414 ⟩
  else ⟨ Compute result of multiply or divide, put it in cur_val 1416 ⟩;
  if arith_error then
    begin print_err("Arithmetic_overflow");
    help2("I_cant_carry_out_that_multiplication_or_division,")
    ("since_the_result_is_out_of_range.");
    if p ≥ glue_val then delete_glue_ref(cur_val);
    error; return;
    end;
  if p < glue_val then sa_word_define(l, cur_val)
  else begin trap_zero_glue; sa_define(l, cur_val)(l, glue_ref, cur_val);
    end;
  exit: end;
```


1413. Here we use the fact that the consecutive codes *int_val* .. *mu_val* and *assign_int* .. *assign_mu_glue* correspond to each other nicely.

```

⟨ Compute the register location l and its type p; but return if invalid 1413 ⟩ ≡
  begin if q ≠ register then
    begin get_x.token;
    if (cur_cmd ≥ assign_int) ∧ (cur_cmd ≤ assign_mu_glue) then
      begin l ← cur_chr; p ← cur_cmd − assign_int; goto found;
      end;
    if cur_cmd ≠ register then
      begin print_err("You can't use "); print_cmd_chr(cur_cmd, cur_chr); print(" after ");
      print_cmd_chr(q, 0); help1("I'm forgetting what you said and not changing anything.");
      error; return;
      end;
    end;
  if (cur_chr < mem_bot) ∨ (cur_chr > lo_mem_stat_max) then
    begin l ← cur_chr; p ← sa_type(l); e ← true;
    end
  else begin p ← cur_chr − mem_bot; scan_register_num;
    if cur_val > 255 then
      begin find_sa_element(p, cur_val, true); l ← cur_ptr; e ← true;
      end
    else case p of
      int_val: l ← cur_val + count_base;
      dimen_val: l ← cur_val + scaled_base;
      glue_val: l ← cur_val + skip_base;
      mu_val: l ← cur_val + mu_skip_base;
      end; { there are no other cases }
    end;
  end;
found: if p < glue_val then if e then w ← sa_int(l) else w ← eqtb[l].int
  else if e then s ← sa_ptr(l) else s ← equiv(l)

```

This code is used in section 1412.

```

1414. ⟨ Compute result of register or advance, put it in cur_val 1414 ⟩ ≡
  if p < glue_val then
    begin if p = int_val then scan_int else scan_normal_dimen;
    if q = advance then cur_val ← cur_val + w;
    end
  else begin scan_glue(p);
    if q = advance then ⟨ Compute the sum of two glue specs 1415 ⟩;
    end

```

This code is used in section 1412.

1415. $\langle \text{Compute the sum of two glue specs } 1415 \rangle \equiv$

```

begin  $q \leftarrow \text{new\_spec}(\text{cur\_val})$ ;  $r \leftarrow s$ ;  $\text{delete\_glue\_ref}(\text{cur\_val})$ ;  $\text{width}(q) \leftarrow \text{width}(q) + \text{width}(r)$ ;
if  $\text{stretch}(q) = 0$  then  $\text{stretch\_order}(q) \leftarrow \text{normal}$ ;
if  $\text{stretch\_order}(q) = \text{stretch\_order}(r)$  then  $\text{stretch}(q) \leftarrow \text{stretch}(q) + \text{stretch}(r)$ 
else if  $(\text{stretch\_order}(q) < \text{stretch\_order}(r)) \wedge (\text{stretch}(r) \neq 0)$  then
    begin  $\text{stretch}(q) \leftarrow \text{stretch}(r)$ ;  $\text{stretch\_order}(q) \leftarrow \text{stretch\_order}(r)$ ;
    end;
if  $\text{shrink}(q) = 0$  then  $\text{shrink\_order}(q) \leftarrow \text{normal}$ ;
if  $\text{shrink\_order}(q) = \text{shrink\_order}(r)$  then  $\text{shrink}(q) \leftarrow \text{shrink}(q) + \text{shrink}(r)$ 
else if  $(\text{shrink\_order}(q) < \text{shrink\_order}(r)) \wedge (\text{shrink}(r) \neq 0)$  then
    begin  $\text{shrink}(q) \leftarrow \text{shrink}(r)$ ;  $\text{shrink\_order}(q) \leftarrow \text{shrink\_order}(r)$ ;
    end;
 $\text{cur\_val} \leftarrow q$ ;
end

```

This code is used in section 1414.

1416. $\langle \text{Compute result of } \textit{multiply} \text{ or } \textit{divide}$, put it in $\textit{cur_val}$ 1416 $\rangle \equiv$

```

begin  $\text{scan\_int}$ ;
if  $p < \text{glue\_val}$  then
    if  $q = \textit{multiply}$  then
        if  $p = \textit{int\_val}$  then  $\text{cur\_val} \leftarrow \text{mult\_integers}(w, \text{cur\_val})$ 
        else  $\text{cur\_val} \leftarrow \text{nx\_plus\_y}(w, \text{cur\_val}, 0)$ 
        else  $\text{cur\_val} \leftarrow \text{x\_over\_n}(w, \text{cur\_val})$ 
    else begin  $r \leftarrow \text{new\_spec}(s)$ ;
        if  $q = \textit{multiply}$  then
            begin  $\text{width}(r) \leftarrow \text{nx\_plus\_y}(\text{width}(s), \text{cur\_val}, 0)$ ;  $\text{stretch}(r) \leftarrow \text{nx\_plus\_y}(\text{stretch}(s), \text{cur\_val}, 0)$ ;
             $\text{shrink}(r) \leftarrow \text{nx\_plus\_y}(\text{shrink}(s), \text{cur\_val}, 0)$ ;
            end
        else begin  $\text{width}(r) \leftarrow \text{x\_over\_n}(\text{width}(s), \text{cur\_val})$ ;  $\text{stretch}(r) \leftarrow \text{x\_over\_n}(\text{stretch}(s), \text{cur\_val})$ ;
             $\text{shrink}(r) \leftarrow \text{x\_over\_n}(\text{shrink}(s), \text{cur\_val})$ ;
            end;
         $\text{cur\_val} \leftarrow r$ ;
    end;
end

```

This code is used in section 1412.

1417. The processing of boxes is somewhat different, because we may need to scan and create an entire box before we actually change the value of the old one.

$\langle \text{Assignments } 1393 \rangle + \equiv$

```

 $\text{set\_box}$ : begin  $\text{scan\_register\_num}$ ;
    if  $\text{global}$  then  $n \leftarrow \text{global\_box\_flag} + \text{cur\_val}$  else  $n \leftarrow \text{box\_flag} + \text{cur\_val}$ ;
     $\text{scan\_optional\_equals}$ ;
    if  $\text{set\_box\_allowed}(n)$ 
else begin  $\text{print\_err}(\text{"Improper"})$ ;  $\text{print\_esc}(\text{"setbox"})$ ;
         $\text{help2}(\text{"Sorry, \setbox is not allowed after \halign in a display,"})$ 
         $(\text{"or between \accent and an accented character."})$ ;  $\text{error}$ ;
    end;
end;

```

1418. The *space_factor* or *prev_depth* settings are changed when a *set_aux* command is sensed. Similarly, *prev_graf* is changed in the presence of *set_prev_graf*, and *dead_cycles* or *insert_penalties* in the presence of *set_page_int*. These definitions are always global.

When some dimension of a box register is changed, the change isn't exactly global; but TEX does not look at the `\global` switch.

⟨ Assignments 1393 ⟩ +≡

```
set_aux: alter_aux;
set_prev_graf: alter_prev_graf;
set_page_dimen: alter_page_so_far;
set_page_int: alter_integer;
set_box_dimen: alter_box_dimen;
```

1419. ⟨ Declare subprocedures for *prefixed_command* 1391 ⟩ +≡

```
procedure alter_aux;
  var c: halfword; { hmode or vmode }
  begin if cur_chr ≠ abs(mode) then report_illegal_case
  else begin c ← cur_chr; scan_optional_equals;
    if c = vmode then
      begin scan_normal_dimen; prev_depth ← cur_val;
      end
    else begin scan_int;
      if (cur_val ≤ 0) ∨ (cur_val > 32767) then
        begin print_err("Bad_space_factor");
          help1("I_allow_only_values_in_the_range_1..32767_here."); int_error(cur_val);
        end
      else space_factor ← cur_val;
      end;
    end;
  end;
```

1420. ⟨ Declare subprocedures for *prefixed_command* 1391 ⟩ +≡

```
procedure alter_prev_graf;
  var p: 0 .. nest_size; { index into nest }
  begin nest[nest_ptr] ← cur_list; p ← nest_ptr;
  while abs(nest[p].mode_field) ≠ vmode do decr(p);
  scan_optional_equals; scan_int;
  if cur_val < 0 then
    begin print_err("Bad_"); print_esc("prevgraf");
      help1("I_allow_only_nonnegative_values_here."); int_error(cur_val);
    end
  else begin nest[p].pg_field ← cur_val; cur_list ← nest[nest_ptr];
    end;
  end;
```

1421. ⟨ Declare subprocedures for *prefixed_command* 1391 ⟩ +≡

```
procedure alter_page_so_far;
  var c: 0 .. 7; { index into page_so_far }
  begin c ← cur_chr; scan_optional_equals; scan_normal_dimen; page_so_far[c] ← cur_val;
  end;
```

1422. \langle Declare subprocedures for *prefixed_command* 1391 $\rangle + \equiv$

```

procedure alter_integer;
  var c: small_number; { 0 for \deadcycles, 1 for \insertpenalties, etc. }
  begin c  $\leftarrow$  cur_chr; scan_optional_equals; scan_int;
  if c = 0 then dead_cycles  $\leftarrow$  cur_val
   $\langle$  Cases for alter_integer 1693  $\rangle$ 
else insert_penalties  $\leftarrow$  cur_val;
  end;

```

1423. \langle Declare subprocedures for *prefixed_command* 1391 $\rangle + \equiv$

```

procedure alter_box_dimen;
  var c: small_number; { width_offset or height_offset or depth_offset }
  b: pointer; { box register }
  begin c  $\leftarrow$  cur_chr; scan_register_num; fetch_box(b); scan_optional_equals; scan_normal_dimen;
  if b  $\neq$  null then mem[b + c].sc  $\leftarrow$  cur_val;
  end;

```

1424. Paragraph shapes are set up in the obvious way.

\langle Assignments 1393 $\rangle + \equiv$

```

set_shape: begin q  $\leftarrow$  cur_chr; scan_optional_equals; scan_int; n  $\leftarrow$  cur_val;
  if n  $\leq$  0 then p  $\leftarrow$  null
  else if q > par_shape_loc then
    begin n  $\leftarrow$  (cur_val div 2) + 1; p  $\leftarrow$  get_node(2 * n + 1); info(p)  $\leftarrow$  n; n  $\leftarrow$  cur_val;
    mem[p + 1].int  $\leftarrow$  n; { number of penalties }
    for j  $\leftarrow$  p + 2 to p + n + 1 do
      begin scan_int; mem[j].int  $\leftarrow$  cur_val; { penalty values }
      end;
    if  $\neg$ odd(n) then mem[p + n + 2].int  $\leftarrow$  0; { unused }
    end
  else begin p  $\leftarrow$  get_node(2 * n + 1); info(p)  $\leftarrow$  n;
    for j  $\leftarrow$  1 to n do
      begin scan_normal_dimen; mem[p + 2 * j - 1].sc  $\leftarrow$  cur_val; { indentation }
      scan_normal_dimen; mem[p + 2 * j].sc  $\leftarrow$  cur_val; { width }
      end;
    end;
  define(q, shape_ref, p);
end;

```

1425. Here's something that isn't quite so obvious. It guarantees that *info*(*par_shape_ptr*) can hold any positive *n* for which *get_node*(2 * *n* + 1) doesn't overflow the memory capacity.

\langle Check the "constant" values for consistency 14 $\rangle + \equiv$

```

if 2 * max_halfword < mem_top - mem_min then bad  $\leftarrow$  41;

```

1426. New hyphenation data is loaded by the *hyph_data* command.

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```

primitive("hyphenation", hyph_data, 0); primitive("patterns", hyph_data, 1);

```

1427. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```

hyph_data: if chr_code = 1 then print_esc("patterns")
  else print_esc("hyphenation");

```

1428. \langle Assignments 1393 $\rangle + \equiv$

```
hyph_data: if cur_chr = 1 then
  begin init new_patterns; goto done; tini
  print_err("Patterns can be loaded only by INITEX"); help0; error;
  repeat get_token;
  until cur_cmd = right_brace; { flush the patterns }
  return;
end
else begin new_hyph_exceptions; goto done;
end;
```

1429. All of TeX's parameters are kept in *eqtb* except the font information, the interaction mode, and the hyphenation tables; these are strictly global.

\langle Assignments 1393 $\rangle + \equiv$

```
assign_font_dimen: begin find_font_dimen(true); k ← cur_val; scan_optional_equals; scan_normal_dimen;
  font_info[k].sc ← cur_val;
end;
assign_font_int: begin n ← cur_chr; scan_font_ident; f ← cur_val;
  if n = no_lig_code then set_no_ligatures(f)
  else if n < lp_code_base then
    begin scan_optional_equals; scan_int;
    if n = 0 then hyphen_char[f] ← cur_val else skew_char[f] ← cur_val;
    end
  else begin scan_char_num; p ← cur_val; scan_optional_equals; scan_int;
    case n of
      lp_code_base: set_lp_code(f, p, cur_val);
      rp_code_base: set_rp_code(f, p, cur_val);
      ef_code_base: set_ef_code(f, p, cur_val);
      tag_code: set_tag_code(f, p, cur_val);
      kn_bs_code_base: set_kn_bs_code(f, p, cur_val);
      st_bs_code_base: set_st_bs_code(f, p, cur_val);
      sh_bs_code_base: set_sh_bs_code(f, p, cur_val);
      kn_bc_code_base: set_kn_bc_code(f, p, cur_val);
      kn_ac_code_base: set_kn_ac_code(f, p, cur_val);
    end;
  end;
end;
```

1430. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$

```
primitive("hyphenchar", assign_font_int, 0); primitive("skewchar", assign_font_int, 1);
primitive("lpcode", assign_font_int, lp_code_base); primitive("rpcode", assign_font_int, rp_code_base);
primitive("efcode", assign_font_int, ef_code_base); primitive("tagcode", assign_font_int, tag_code);
primitive("knbscode", assign_font_int, kn_bs_code_base);
primitive("stbscode", assign_font_int, st_bs_code_base);
primitive("shbscode", assign_font_int, sh_bs_code_base);
primitive("knbccode", assign_font_int, kn_bc_code_base);
primitive("knaccode", assign_font_int, kn_ac_code_base);
primitive("pdfnoligatures", assign_font_int, no_lig_code);
```

1431. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
assign_font_int: case chr_code of
  0: print_esc("hyphenchar");
  1: print_esc("skewchar");
  lp_code_base: print_esc("lpcode");
  rp_code_base: print_esc("rpcode");
  ef_code_base: print_esc("efcode");
  tag_code: print_esc("tagcode");
  kn_bs_code_base: print_esc("knbscode");
  st_bs_code_base: print_esc("stbscode");
  sh_bs_code_base: print_esc("shbscode");
  kn_bc_code_base: print_esc("knbccode");
  kn_ac_code_base: print_esc("knaccode");
  no_lig_code: print_esc("pdfnoligatures");
endcases;
```

1432. Here is where the information for a new font gets loaded.

\langle Assignments 1393 $\rangle + \equiv$

```
def_font: new_font(a);
letterspace_font: new_letterspaced_font(a);
pdf_copy_font: make_font_copy(a);
```

1433. \langle Declare subprocedures for *prefixed_command* 1391 $\rangle + \equiv$

```
procedure new_font(a : small_number);
  label common_ending;
  var u: pointer; { user's font identifier }
      s: scaled; { stated "at" size, or negative of scaled magnification }
      f: internal_font_number; { runs through existing fonts }
      t: str_number; { name for the frozen font identifier }
      old_setting: 0 .. max_selector; { holds selector setting }
      flushable_string: str_number; { string not yet referenced }
  begin if job_name = 0 then open_log_file; { avoid confusing texput with the font name }
  get_r_token; u  $\leftarrow$  cur_cs;
  if u  $\geq$  hash_base then t  $\leftarrow$  text(u)
  else if u  $\geq$  single_base then
    if u = null_cs then t  $\leftarrow$  "FONT" else t  $\leftarrow$  u - single_base
    else begin old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string; print("FONT"); print(u - active_base);
      selector  $\leftarrow$  old_setting; str_room(1); t  $\leftarrow$  make_string;
    end;
    define(u, set_font, null_font); scan_optional_equals; scan_file_name;
   $\langle$  Scan the font size specification 1434  $\rangle$ ;
   $\langle$  If this font has already been loaded, set f to the internal font number and goto common_ending 1436  $\rangle$ ;
  f  $\leftarrow$  read_font_info(u, cur_name, cur_area, s);
  common_ending: define(u, set_font, f); eqtb[font_id_base + f]  $\leftarrow$  eqtb[u]; font_id_text(f)  $\leftarrow$  t;
  end;
```

1434. \langle Scan the font size specification 1434 $\rangle \equiv$

```

name_in_progress  $\leftarrow$  true; { this keeps cur_name from being changed }
if scan_keyword("at") then  $\langle$  Put the (positive) 'at' size into s 1435  $\rangle$ 
else if scan_keyword("scaled") then
  begin scan_int; s  $\leftarrow$  -cur_val;
  if (cur_val  $\leq$  0)  $\vee$  (cur_val > 32768) then
    begin print_err("Illegal_magnification_has_been_changed_to_1000");
    help1("The_magnification_ratio_must_be_between_1_and_32768."); int_error(cur_val);
    s  $\leftarrow$  -1000;
    end;
  end
else s  $\leftarrow$  -1000;
name_in_progress  $\leftarrow$  false

```

This code is used in section 1433.

1435. \langle Put the (positive) 'at' size into s 1435 $\rangle \equiv$

```

begin scan_normal_dimen; s  $\leftarrow$  cur_val;
if (s  $\leq$  0)  $\vee$  (s  $\geq$  '1000000000') then
  begin print_err("Improper_at_size()"); print_scaled(s); print("pt),_replaced_by_10pt");
  help2("I_can_only_handle_fonts_at_positive_sizes_that_are")
  ("less_than_2048pt,_so_I've_changed_what_you_said_to_10pt."); error; s  $\leftarrow$  10 * unity;
  end;
end

```

This code is used in section 1434.

1436. When the user gives a new identifier to a font that was previously loaded, the new name becomes the font identifier of record. Font names 'xyz' and 'XYZ' are considered to be different.

\langle If this font has already been loaded, set f to the internal font number and **goto** common_ending 1436 $\rangle \equiv$

```

flushable_string  $\leftarrow$  str_ptr - 1;
for f  $\leftarrow$  font_base + 1 to font_ptr do
  if str_eq_str(font_name[f], cur_name)  $\wedge$  str_eq_str(font_area[f], cur_area) then
    begin if cur_name = flushable_string then
      begin flush_string; cur_name  $\leftarrow$  font_name[f];
      end;
    if s > 0 then
      begin if s = font_size[f] then goto common_ending;
      end
    else if font_size[f] = xn_over_d(font_dsize[f], -s, 1000) then goto common_ending;
    end

```

This code is used in section 1433.

1437. \langle Cases of print_cmd_chr for symbolic printing of primitives 245 $\rangle + \equiv$

```

set_font: begin print("select_font"); slow_print(font_name[chr_code]);
if font_size[chr_code]  $\neq$  font_dsize[chr_code] then
  begin print("_at_"); print_scaled(font_size[chr_code]); print("pt");
  end;
end;

```

1438. \langle Put each of \TeX 's primitives into the hash table 244 $\rangle + \equiv$
`primitive("batchmode", set_interaction, batch_mode);`
`primitive("nonstopmode", set_interaction, nonstop_mode);`
`primitive("scrollmode", set_interaction, scroll_mode);`
`primitive("errorstopmode", set_interaction, error_stop_mode);`

1439. \langle Cases of `print_cmd_chr` for symbolic printing of primitives 245 $\rangle + \equiv$
`set_interaction: case chr_code of`
`batch_mode: print_esc("batchmode");`
`nonstop_mode: print_esc("nonstopmode");`
`scroll_mode: print_esc("scrollmode");`
`othercases print_esc("errorstopmode")`
`endcases;`

1440. \langle Assignments 1393 $\rangle + \equiv$
`set_interaction: new_interaction;`

1441. \langle Declare subprocedures for `prefixed_command` 1391 $\rangle + \equiv$
`procedure new_interaction;`
`begin print_ln; interaction \leftarrow cur_chr; \langle Initialize the print selector based on interaction 75 \rangle ;`
`if log_opened then selector \leftarrow selector + 2;`
`end;`

1442. The `\afterassignment` command puts a token into the global variable `after_token`. This global variable is examined just after every assignment has been performed.

\langle Global variables 13 $\rangle + \equiv$
`after_token: halfword; { zero, or a saved token }`

1443. \langle Set initial values of key variables 21 $\rangle + \equiv$
`after_token \leftarrow 0;`

1444. \langle Cases of `main_control` that don't depend on `mode` 1386 $\rangle + \equiv$
`any_mode(after_assignment): begin get_token; after_token \leftarrow cur_tok;`
`end;`

1445. \langle Insert a token saved by `\afterassignment`, if any 1445 $\rangle \equiv$
`if after_token \neq 0 then`
`begin cur_tok \leftarrow after_token; back_input; after_token \leftarrow 0;`
`end`

This code is used in section 1387.

1446. Here is a procedure that might be called 'Get the next non-blank non-relax non-call non-assignment token'.

\langle Declare action procedures for use by `main_control` 1219 $\rangle + \equiv$
`procedure do_assignments;`
`label exit;`
`begin loop`
`begin \langle Get the next non-blank non-relax non-call token 430 \rangle ;`
`if cur_cmd \leq max_non_prefixed_command then return;`
`set_box_allowed \leftarrow false; prefixed_command; set_box_allowed \leftarrow true;`
`end;`
`exit: end;`

1447. \langle Cases of *main_control* that don't depend on *mode* 1386 $\rangle + \equiv$
any_mode(after_group): **begin** *get_token*; *save_for_after(cur_tok)*;
end;

1448. Files for `\read` are opened and closed by the *in_stream* command.

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$
primitive("openin", in_stream, 1); primitive("closein", in_stream, 0);

1449. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
in_stream: if chr_code = 0 then print_esc("closein")
else *print_esc("openin")*;

1450. \langle Cases of *main_control* that don't depend on *mode* 1386 $\rangle + \equiv$
any_mode(in_stream): open_or_close_in;

1451. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

procedure *open_or_close_in*;
var *c*: 0 .. 1; { 1 for `\openin`, 0 for `\closein` }
n: 0 .. 15; { stream number }
begin *c* \leftarrow *cur_chr*; *scan_four_bit_int*; *n* \leftarrow *cur_val*;
if *read_open[n]* \neq *closed* **then**
begin *a_close(read_file[n])*; *read_open[n]* \leftarrow *closed*;
end;
if *c* \neq 0 **then**
begin *scan_optional_equals*; *scan_file_name*;
if *cur_ext* = "" **then** *cur_ext* \leftarrow ".tex";
pack_cur_name;
if *a_open_in(read_file[n])* **then** *read_open[n]* \leftarrow *just_open*;
end;
end;

1452. The user can issue messages to the terminal, regardless of the current mode.

\langle Cases of *main_control* that don't depend on *mode* 1386 $\rangle + \equiv$
any_mode(message): issue_message;

1453. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$
primitive("message", message, 0); primitive("errmessage", message, 1);

1454. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
message: if chr_code = 0 then print_esc("message")
else *print_esc("errmessage")*;

1455. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure issue_message;
  var old_setting: 0 .. max_selector; { holds selector setting }
  c: 0 .. 1; { identifies \message and \errmessage }
  s: str_number; { the message }
  begin c  $\leftarrow$  cur_chr; link(garbage)  $\leftarrow$  scan_toks(false, true); old_setting  $\leftarrow$  selector;
  selector  $\leftarrow$  new_string; token_show(def_ref); selector  $\leftarrow$  old_setting; flush_list(def_ref); str_room(1);
  s  $\leftarrow$  make_string;
  if c = 0 then  $\langle$  Print string s on the terminal 1456  $\rangle$ 
  else  $\langle$  Print string s as an error message 1459  $\rangle$ ;
  flush_string;
end;
```

1456. \langle Print string *s* on the terminal 1456 $\rangle \equiv$

```
begin if term_offset + length(s) > max_print_line - 2 then println
else if (term_offset > 0)  $\vee$  (file_offset > 0) then print_char(" ");
  slow_print(s); update_terminal;
end
```

This code is used in section 1455.

1457. If `\errmessage` occurs often in *scroll_mode*, without user-defined `\errhelp`, we don't want to give a long help message each time. So we give a verbose explanation only once.

\langle Global variables 13 $\rangle + \equiv$

long_help_seen: *boolean*; { has the long `\errmessage` help been used? }

1458. \langle Set initial values of key variables 21 $\rangle + \equiv$

long_help_seen \leftarrow *false*;

1459. \langle Print string *s* as an error message 1459 $\rangle \equiv$

```
begin print_err(""); slow_print(s);
if err_help  $\neq$  null then use_err_help  $\leftarrow$  true
else if long_help_seen then help1("(That was another \errmessage.)")
  else begin if interaction < error_stop_mode then long_help_seen  $\leftarrow$  true;
    help4("This error message was generated by an \errmessage")
    ("command, so I can't give any explicit help.")
    ("Pretend that you're Hercule Poirot: Examine all clues,")
    ("and deduce the truth by order and method.");
  end;
  error; use_err_help  $\leftarrow$  false;
end
```

This code is used in section 1455.

1460. The *error* routine calls on *give_err_help* if help is requested from the *err_help* parameter.

procedure *give_err_help*;

```
begin token_show(err_help);
end;
```

1461. The `\uppercase` and `\lowercase` commands are implemented by building a token list and then changing the cases of the letters in it.

\langle Cases of *main_control* that don't depend on *mode* 1386 $\rangle + \equiv$

any_mode(*case_shift*): *shift_case*;

1462. \langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$
`primitive("lowercase", case_shift, lc_code_base); primitive("uppercase", case_shift, uc_code_base);`

1463. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
`case_shift: if chr_code = lc_code_base then print_esc("lowercase")
 else print_esc("uppercase");`

1464. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
procedure *shift_case*;

```

var b: pointer; { lc_code_base or uc_code_base }
p: pointer; { runs through the token list }
t: halfword; { token }
c: eight_bits; { character code }
begin b ← cur_chr; p ← scan_toks(false, false); p ← link(def_ref);
while p ≠ null do
  begin  $\langle$  Change the case of the token in p, if a change is appropriate 1465  $\rangle$ ;
    p ← link(p);
  end;
back_list(link(def_ref)); free_avail(def_ref); { omit reference count }
end;
```

1465. When the case of a *chr_code* changes, we don't change the *cmd*. We also change active characters, using the fact that *cs_token_flag* + *active_base* is a multiple of 256.

\langle Change the case of the token in *p*, if a change is appropriate 1465 $\rangle \equiv$
`t ← info(p);
if t < cs_token_flag + single_base then
 begin c ← t mod 256;
 if equiv(b + c) ≠ 0 then info(p) ← t - c + equiv(b + c);
 end`

This code is used in section 1464.

1466. We come finally to the last pieces missing from *main_control*, namely the '\show' commands that are useful when debugging.

\langle Cases of *main_control* that don't depend on *mode* 1386 $\rangle + \equiv$
`any_mode(xray): show_whatever;`

1467. `define show_code = 0 { \show }
define show_box_code = 1 { \showbox }
define show_the_code = 2 { \showthe }
define show_lists_code = 3 { \showlists }`

\langle Put each of TeX's primitives into the hash table 244 $\rangle + \equiv$
`primitive("show", xray, show_code); primitive("showbox", xray, show_box_code);
primitive("showthe", xray, show_the_code); primitive("showlists", xray, show_lists_code);`

1468. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
xray: case chr_code of
  show_box_code: print_esc("showbox");
  show_the_code: print_esc("showthe");
  show_lists_code: print_esc("showlists");
   $\langle$  Cases of xray for print_cmd_chr 1673  $\rangle$ 
othercases print_esc("show")
endcases;
```

1469. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$

```
procedure show_whatever;
  label common_ending;
  var p: pointer; { tail of a token list to show }
      t: small_number; { type of conditional being shown }
      m: normal .. or_code; { upper bound on fi_or_else codes }
      l: integer; { line where that conditional began }
      n: integer; { level of \if... \fi nesting }
  begin case cur_chr of
    show_lists_code: begin begin_diagnostic; show_activities;
      end;
    show_box_code:  $\langle$  Show the current contents of a box 1472  $\rangle$ ;
    show_code:  $\langle$  Show the current meaning of a token, then goto common_ending 1470  $\rangle$ ;
       $\langle$  Cases for show_whatever 1674  $\rangle$ 
    othercases  $\langle$  Show the current value of some parameter or register, then goto common_ending 1473  $\rangle$ 
    endcases;
     $\langle$  Complete a potentially long \show command 1474  $\rangle$ ;
  common_ending: if interaction < error_stop_mode then
    begin help0; decr(error_count);
    end
  else if tracing_online > 0 then
    begin
      help3("This isn't an error message; I'm just showing something.")
      ("Type `I\show...` to show more (e.g., \show\cs,")
      ("\showthe\count10, \showbox255, \showlists).");
    end
  else begin
    help5("This isn't an error message; I'm just showing something.")
    ("Type `I\show...` to show more (e.g., \show\cs,")
    ("\showthe\count10, \showbox255, \showlists).")
    ("And type `I\tracingonline=1\show...` to show boxes and")
    ("lists on your terminal as well as in the transcript file.");
  end;
  error;
end;
```

1470. \langle Show the current meaning of a token, then **goto** *common_ending* 1470 $\rangle \equiv$

```
begin get_token;
if interaction = error_stop_mode then wake_up_terminal;
print_nl(">");
if cur_cs  $\neq$  0 then
  begin sprint_cs(cur_cs); print_char("=");
  end;
print_meaning; goto common_ending;
end
```

This code is used in section 1469.

1471. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$

```
undefined_cs: print("undefined");
call, long_call, outer_call, long_outer_call: begin n  $\leftarrow$  cmd - call;
  if info(link(chr_code)) = protected_token then n  $\leftarrow$  n + 4;
  if odd(n div 4) then print_esc("protected");
  if odd(n) then print_esc("long");
  if odd(n div 2) then print_esc("outer");
  if n > 0 then print_char("_");
  print("macro");
  end;
end_template: print_esc("outer_endtemplate");
```

1472. \langle Show the current contents of a box 1472 $\rangle \equiv$

```
begin scan_register_num; fetch_box(p); begin_diagnostic; print_nl("> \box"); print_int(cur_val);
print_char("=");
if p = null then print("void") else show_box(p);
end
```

This code is used in section 1469.

1473. \langle Show the current value of some parameter or register, then **goto** *common_ending* 1473 $\rangle \equiv$

```
begin p  $\leftarrow$  the_toks;
if interaction = error_stop_mode then wake_up_terminal;
print_nl(">"); token_show(temp_head); flush_list(link(temp_head)); goto common_ending;
end
```

This code is used in section 1469.

1474. \langle Complete a potentially long `\show` command 1474 $\rangle \equiv$

```
end_diagnostic(true); print_err("OK");
if selector = term_and_log then
  if tracing_online  $\leq$  0 then
    begin selector  $\leftarrow$  term_only; print("_(see_the_transcript_file)"); selector  $\leftarrow$  term_and_log;
    end
```

This code is used in section 1469.

1475. Dumping and undumping the tables. After INITEX has seen a collection of fonts and macros, it can write all the necessary information on an auxiliary file so that production versions of T_EX are able to initialize their memory at high speed. The present section of the program takes care of such output and input. We shall consider simultaneously the processes of storing and restoring, so that the inverse relation between them is clear.

The global variable *format.ident* is a string that is printed right after the *banner* line when T_EX is ready to start. For INITEX this string says simply ‘ (INITEX)’; for other versions of T_EX it says, for example, ‘ (preloaded format=plain 1982.11.19)’, showing the year, month, and day that the format file was created. We have *format.ident* = 0 before T_EX’s tables are loaded.

```
⟨Global variables 13⟩ +≡
format.ident: str_number;
```

1476. ⟨Set initial values of key variables 21⟩ +≡
format.ident ← 0;

1477. ⟨Initialize table entries (done by INITEX only) 182⟩ +≡
format.ident ← "␣(INITEX)";

1478. ⟨Declare action procedures for use by *main.control* 1219⟩ +≡
init procedure *store_fmt_file*;
label *found1*, *found2*, *done1*, *done2*;
var *j, k, l*: *integer*; {all-purpose indices}
 p, q: *pointer*; {all-purpose pointers}
 x: *integer*; {something to dump}
 w: *four_quarters*; {four ASCII codes}
begin ⟨If dumping is not allowed, abort 1480⟩;
 ⟨Create the *format.ident*, open the format file, and inform the user that dumping has begun 1506⟩;
 ⟨Dump constants for consistency check 1483⟩;
 ⟨Dump the string pool 1485⟩;
 ⟨Dump the dynamic memory 1487⟩;
 ⟨Dump the table of equivalents 1489⟩;
 ⟨Dump the font information 1496⟩;
 ⟨Dump the hyphenation tables 1500⟩;
 ⟨Dump pdftex data 1502⟩;
 ⟨Dump a couple more things and the closing check word 1504⟩;
 ⟨Close the format file 1507⟩;
end;
tini

1479. Corresponding to the procedure that dumps a format file, we have a function that reads one in. The function returns *false* if the dumped format is incompatible with the present TeX table sizes, etc.

```

define bad_fmt = 6666 { go here if the format file is unacceptable }
define too_small(#) ≡
    begin wake_up_terminal; wterm_ln(`---!_Must_increase_the_,#); goto bad_fmt;
    end

⟨ Declare the function called open_fmt_file 550 ⟩
function load_fmt_file: boolean;
    label bad_fmt, exit;
    var j, k: integer; { all-purpose indices }
        p, q: pointer; { all-purpose pointers }
        x: integer; { something undumped }
        w: four_quarters; { four ASCII codes }
    begin ⟨ Undump constants for consistency check 1484 ⟩;
    ⟨ Undump the string pool 1486 ⟩;
    ⟨ Undump the dynamic memory 1488 ⟩;
    ⟨ Undump the table of equivalents 1490 ⟩;
    ⟨ Undump the font information 1497 ⟩;
    ⟨ Undump the hyphenation tables 1501 ⟩;
    ⟨ Undump pdftex data 1503 ⟩;
    ⟨ Undump a couple more things and the closing check word 1505 ⟩;
    prev_depth ← pdf_ignored_dimen; load_fmt_file ← true; return; { it worked! }
bad_fmt: wake_up_terminal; wterm_ln(`(Fatal_format_file_error;_I'm_stymied)`);
    load_fmt_file ← false;
exit: end;

```

1480. The user is not allowed to dump a format file unless *save_ptr* = 0. This condition implies that *cur_level* = *level_one*, hence the *req_level* array is constant and it need not be dumped.

```

⟨ If dumping is not allowed, abort 1480 ⟩ ≡
    if save_ptr ≠ 0 then
        begin print_err("You_can't_dump_inside_a_group"); help1(" {...\dump}_is_a_no-no.");
        succumb;
    end

```

This code is used in section 1478.

1481. Format files consist of *memory_word* items, and we use the following macros to dump words of different types:

```

define dump_wd(#) ≡
    begin fmt_file↑ ← #; put(fmt_file); end
define dump_int(#) ≡
    begin fmt_file↑.int ← #; put(fmt_file); end
define dump_hh(#) ≡
    begin fmt_file↑.hh ← #; put(fmt_file); end
define dump_qqqq(#) ≡
    begin fmt_file↑.qqqq ← #; put(fmt_file); end

⟨ Global variables 13 ⟩ +≡
fmt_file: word_file; { for input or output of format information }

```

1482. The inverse macros are slightly more complicated, since we need to check the range of the values we are reading in. We say ‘*undump(a)(b)(x)*’ to read an integer value x that is supposed to be in the range $a \leq x \leq b$. System error messages should be suppressed when undumping.

```

define undump_wd(#) ≡
  begin get(fmt_file); # ← fmt_file↑; end
define undump_int(#) ≡
  begin get(fmt_file); # ← fmt_file↑.int; end
define undump_hh(#) ≡
  begin get(fmt_file); # ← fmt_file↑.hh; end
define undump_qqqq(#) ≡
  begin get(fmt_file); # ← fmt_file↑.qqqq; end
define undump_end_end(#) ≡ # ← x; end
define undump_end(#) ≡ (x > #) then goto bad_fmt else undump_end_end
define undump(#) ≡
  begin undump_int(x);
  if (x < #) ∨ undump_end
define undump_size_end_end(#) ≡ too_small(#) else undump_end_end
define undump_size_end(#) ≡
  if x > # then undump_size_end_end
define undump_size(#) ≡
  begin undump_int(x);
  if x < # then goto bad_fmt;
  undump_size_end

```

1483. The next few sections of the program should make it clear how we use the dump/undump macros.

⟨ Dump constants for consistency check 1483 ⟩ ≡

```

dump_int(@$);
⟨ Dump the ε-TeX state 1651 ⟩
dump_int(mem_bot);
dump_int(mem_top);
dump_int(eqtb_size);
dump_int(hash_prime);
dump_int(hyph_size)

```

This code is used in section 1478.

1484. Sections of a WEB program that are “commented out” still contribute strings to the string pool; therefore INITEX and TeX will have the same strings. (And it is, of course, a good thing that they do.)

```

⟨ Undump constants for consistency check 1484 ⟩ ≡
   $x \leftarrow \text{fmt\_file} \uparrow .\text{int};$ 
  if  $x \neq \text{\textcircled{e}}\$$  then goto bad_fmt; { check that strings are the same }
  ⟨ Undump the  $\varepsilon$ -TeX state 1652 ⟩
  undump_int( $x$ );
  if  $x \neq \text{mem\_bot}$  then goto bad_fmt;
  undump_int( $x$ );
  if  $x \neq \text{mem\_top}$  then goto bad_fmt;
  undump_int( $x$ );
  if  $x \neq \text{eqtb\_size}$  then goto bad_fmt;
  undump_int( $x$ );
  if  $x \neq \text{hash\_prime}$  then goto bad_fmt;
  undump_int( $x$ );
  if  $x \neq \text{hyph\_size}$  then goto bad_fmt

```

This code is used in section 1479.

1485. define *dump_four_ASCII* $\equiv w.b0 \leftarrow qi(so(str_pool[k])); w.b1 \leftarrow qi(so(str_pool[k+1]));$
 $w.b2 \leftarrow qi(so(str_pool[k+2])); w.b3 \leftarrow qi(so(str_pool[k+3])); dump_qqqq(w)$

```

⟨ Dump the string pool 1485 ⟩ ≡
  dump_int(pool_ptr); dump_int(str_ptr);
  for  $k \leftarrow 0$  to str_ptr do dump_int(str_start[ $k$ ]);
   $k \leftarrow 0$ ;
  while  $k + 4 < pool\_ptr$  do
    begin dump_four_ASCII;  $k \leftarrow k + 4$ ;
    end;
   $k \leftarrow pool\_ptr - 4$ ; dump_four_ASCII; print_ln; print_int(str_ptr);
  print("␣strings␣of␣total␣length␣"); print_int(pool_ptr)

```

This code is used in section 1478.

1486. define *undump_four_ASCII* $\equiv undump_qqqq(w); str_pool[k] \leftarrow si(qo(w.b0));$
 $str_pool[k+1] \leftarrow si(qo(w.b1)); str_pool[k+2] \leftarrow si(qo(w.b2)); str_pool[k+3] \leftarrow si(qo(w.b3))$

```

⟨ Undump the string pool 1486 ⟩ ≡
  undump_size(0)(pool_size)('string␣pool␣size')(pool_ptr);
  undump_size(0)(max_strings)('max␣strings')(str_ptr);
  for  $k \leftarrow 0$  to str_ptr do undump(0)(pool_ptr)(str_start[ $k$ ]);
   $k \leftarrow 0$ ;
  while  $k + 4 < pool\_ptr$  do
    begin undump_four_ASCII;  $k \leftarrow k + 4$ ;
    end;
   $k \leftarrow pool\_ptr - 4$ ; undump_four_ASCII; init_str_ptr  $\leftarrow str\_ptr$ ; init_pool_ptr  $\leftarrow pool\_ptr$ 

```

This code is used in section 1479.

1487. By sorting the list of available spaces in the variable-size portion of *mem*, we are usually able to get by without having to dump very much of the dynamic memory.

We recompute *var_used* and *dyn_used*, so that INITEX dumps valid information even when it has not been gathering statistics.

```

⟨Dump the dynamic memory 1487⟩ ≡
  sort_avail; var_used ← 0; dump_int(lo_mem_max); dump_int(rover);
  if eTeX_ex then
    for k ← int_val to tok_val do dump_int(sa_root[k]);
  p ← mem_bot; q ← rover; x ← 0;
  repeat for k ← p to q + 1 do dump_wd(mem[k]);
    x ← x + q + 2 - p; var_used ← var_used + q - p; p ← q + node_size(q); q ← rlink(q);
  until q = rover;
  var_used ← var_used + lo_mem_max - p; dyn_used ← mem_end + 1 - hi_mem_min;
  for k ← p to lo_mem_max do dump_wd(mem[k]);
  x ← x + lo_mem_max + 1 - p; dump_int(hi_mem_min); dump_int(avail);
  for k ← hi_mem_min to mem_end do dump_wd(mem[k]);
  x ← x + mem_end + 1 - hi_mem_min; p ← avail;
  while p ≠ null do
    begin decr(dyn_used); p ← link(p);
    end;
  dump_int(var_used); dump_int(dyn_used); print_ln; print_int(x);
  print("memory_locations_dumped;current_usage_is"); print_int(var_used); print_char("&");
  print_int(dyn_used)

```

This code is used in section 1478.

```

1488. ⟨Undump the dynamic memory 1488⟩ ≡
  undump(lo_mem_stat_max + 1000)(hi_mem_stat_min - 1)(lo_mem_max);
  undump(lo_mem_stat_max + 1)(lo_mem_max)(rover);
  if eTeX_ex then
    for k ← int_val to tok_val do undump(null)(lo_mem_max)(sa_root[k]);
  p ← mem_bot; q ← rover;
  repeat for k ← p to q + 1 do undump_wd(mem[k]);
    p ← q + node_size(q);
    if (p > lo_mem_max) ∨ ((q ≥ rlink(q)) ∧ (rlink(q) ≠ rover)) then goto bad_fmt;
    q ← rlink(q);
  until q = rover;
  for k ← p to lo_mem_max do undump_wd(mem[k]);
  if mem_min < mem_bot - 2 then { make more low memory available }
    begin p ← llink(rover); q ← mem_min + 1; link(mem_min) ← null; info(mem_min) ← null;
      { we don't use the bottom word }
    rlink(p) ← q; llink(rover) ← q;
    rlink(q) ← rover; llink(q) ← p; link(q) ← empty_flag; node_size(q) ← mem_bot - q;
    end;
  undump(lo_mem_max + 1)(hi_mem_stat_min)(hi_mem_min); undump(null)(mem_top)(avail);
  mem_end ← mem_top;
  for k ← hi_mem_min to mem_end do undump_wd(mem[k]);
  undump_int(var_used); undump_int(dyn_used)

```

This code is used in section 1479.

1489. $\langle \text{Dump the table of equivalents 1489} \rangle \equiv$
 $\langle \text{Dump regions 1 to 4 of eqtb 1491} \rangle;$
 $\langle \text{Dump regions 5 and 6 of eqtb 1492} \rangle;$
 $\text{dump_int}(\text{par_loc}); \text{dump_int}(\text{write_loc});$
 $\langle \text{Dump the hash table 1494} \rangle$

This code is used in section 1478.

1490. $\langle \text{Undump the table of equivalents 1490} \rangle \equiv$
 $\langle \text{Undump regions 1 to 6 of eqtb 1493} \rangle;$
 $\text{undump}(\text{hash_base})(\text{frozen_control_sequence})(\text{par_loc}); \text{par_token} \leftarrow \text{cs_token_flag} + \text{par_loc};$
 $\text{undump}(\text{hash_base})(\text{frozen_control_sequence})(\text{write_loc});$
 $\langle \text{Undump the hash table 1495} \rangle$

This code is used in section 1479.

1491. The table of equivalents usually contains repeated information, so we dump it in compressed form: The sequence of $n+2$ values (n, x_1, \dots, x_n, m) in the format file represents $n+m$ consecutive entries of *eqtb*, with m extra copies of x_n , namely $(x_1, \dots, x_n, x_n, \dots, x_n)$.

$\langle \text{Dump regions 1 to 4 of eqtb 1491} \rangle \equiv$
 $k \leftarrow \text{active_base};$
repeat $j \leftarrow k;$
 while $j < \text{int_base} - 1$ **do**
 begin if $(\text{equiv}(j) = \text{equiv}(j+1)) \wedge (\text{eq_type}(j) = \text{eq_type}(j+1)) \wedge (\text{eq_level}(j) = \text{eq_level}(j+1))$
 then goto *found1*;
 $\text{incr}(j);$
 end;
 $l \leftarrow \text{int_base}; \text{goto } \text{done1}; \{ j = \text{int_base} - 1 \}$
found1: $\text{incr}(j); l \leftarrow j;$
 while $j < \text{int_base} - 1$ **do**
 begin if $(\text{equiv}(j) \neq \text{equiv}(j+1)) \vee (\text{eq_type}(j) \neq \text{eq_type}(j+1)) \vee (\text{eq_level}(j) \neq \text{eq_level}(j+1))$
 then goto *done1*;
 $\text{incr}(j);$
 end;
done1: $\text{dump_int}(l - k);$
 while $k < l$ **do**
 begin $\text{dump_wd}(\text{eqtb}[k]); \text{incr}(k);$
 end;
 $k \leftarrow j + 1; \text{dump_int}(k - l);$
until $k = \text{int_base}$

This code is used in section 1489.

1492. $\langle \text{Dump regions 5 and 6 of } eqtb \text{ 1492} \rangle \equiv$

```

repeat  $j \leftarrow k$ ;
  while  $j < eqtb\_size$  do
    begin if  $eqtb[j].int = eqtb[j+1].int$  then goto found2;
    incr( $j$ );
    end;
     $l \leftarrow eqtb\_size + 1$ ; goto done2; {  $j = eqtb\_size$  }
found2: incr( $j$ );  $l \leftarrow j$ ;
  while  $j < eqtb\_size$  do
    begin if  $eqtb[j].int \neq eqtb[j+1].int$  then goto done2;
    incr( $j$ );
    end;
done2: dump_int( $l - k$ );
  while  $k < l$  do
    begin dump_wd( $eqtb[k]$ ); incr( $k$ );
    end;
     $k \leftarrow j + 1$ ; dump_int( $k - l$ );
until  $k > eqtb\_size$ 

```

This code is used in section 1489.

1493. $\langle \text{Undump regions 1 to 6 of } eqtb \text{ 1493} \rangle \equiv$

```

 $k \leftarrow active\_base$ ;
repeat undump_int( $x$ );
  if  $(x < 1) \vee (k + x > eqtb\_size + 1)$  then goto bad_fmt;
  for  $j \leftarrow k$  to  $k + x - 1$  do undump_wd( $eqtb[j]$ );
   $k \leftarrow k + x$ ; undump_int( $x$ );
  if  $(x < 0) \vee (k + x > eqtb\_size + 1)$  then goto bad_fmt;
  for  $j \leftarrow k$  to  $k + x - 1$  do  $eqtb[j] \leftarrow eqtb[k - 1]$ ;
   $k \leftarrow k + x$ ;
until  $k > eqtb\_size$ 

```

This code is used in section 1490.

1494. A different scheme is used to compress the hash table, since its lower region is usually sparse. When $text(p) \neq 0$ for $p \leq hash_used$, we output two words, p and $hash[p]$. The hash table is, of course, densely packed for $p \geq hash_used$, so the remaining entries are output in a block.

$\langle \text{Dump the hash table 1494} \rangle \equiv$

```

for  $p \leftarrow 0$  to prim_size do dump_hh(prim[p]);
dump_int(hash_used); cs_count  $\leftarrow$  frozen_control_sequence - 1 - hash_used;
for  $p \leftarrow hash\_base$  to hash_used do
  if  $text(p) \neq 0$  then
    begin dump_int(p); dump_hh(hash[p]); incr(cs_count);
    end;
for  $p \leftarrow hash\_used + 1$  to undefined_control_sequence - 1 do dump_hh(hash[p]);
dump_int(cs_count);
print_ln; print_int(cs_count); print("_multiletter_control_sequences")

```

This code is used in section 1489.

1495. \langle Undump the hash table 1495 $\rangle \equiv$

```

for  $p \leftarrow 0$  to  $\text{prim\_size}$  do  $\text{undump\_hh}(\text{prim}[p]);$ 
 $\text{undump}(\text{hash\_base})(\text{frozen\_control\_sequence})(\text{hash\_used});$   $p \leftarrow \text{hash\_base} - 1;$ 
repeat  $\text{undump}(p + 1)(\text{hash\_used})(p);$   $\text{undump\_hh}(\text{hash}[p]);$ 
until  $p = \text{hash\_used};$ 
for  $p \leftarrow \text{hash\_used} + 1$  to  $\text{undefined\_control\_sequence} - 1$  do  $\text{undump\_hh}(\text{hash}[p]);$ 
 $\text{undump\_int}(\text{cs\_count})$ 

```

This code is used in section 1490.

1496. \langle Dump the font information 1496 $\rangle \equiv$

```

 $\text{dump\_int}(\text{fmem\_ptr});$ 
for  $k \leftarrow 0$  to  $\text{fmem\_ptr} - 1$  do  $\text{dump\_wd}(\text{font\_info}[k]);$ 
 $\text{dump\_int}(\text{font\_ptr});$ 
for  $k \leftarrow \text{null\_font}$  to  $\text{font\_ptr}$  do  $\langle$  Dump the array info for internal font number  $k$  1498  $\rangle;$ 
 $\text{print\_ln};$   $\text{print\_int}(\text{fmem\_ptr} - 7);$   $\text{print}(\text{"\_words\_of\_font\_info\_for\_"});$ 
 $\text{print\_int}(\text{font\_ptr} - \text{font\_base});$   $\text{print}(\text{"\_preloaded\_font"});$ 
if  $\text{font\_ptr} \neq \text{font\_base} + 1$  then  $\text{print\_char}(\text{"s"})$ 

```

This code is used in section 1478.

1497. \langle Undump the font information 1497 $\rangle \equiv$

```

 $\text{undump\_size}(7)(\text{font\_mem\_size})(\text{"font\_mem\_size"})(\text{fmem\_ptr});$ 
for  $k \leftarrow 0$  to  $\text{fmem\_ptr} - 1$  do  $\text{undump\_wd}(\text{font\_info}[k]);$ 
 $\text{undump\_size}(\text{font\_base})(\text{font\_max})(\text{"font\_max"})(\text{font\_ptr});$ 
for  $k \leftarrow \text{null\_font}$  to  $\text{font\_ptr}$  do  $\langle$  Undump the array info for internal font number  $k$  1499  $\rangle$ 

```

This code is used in section 1479.

1498. \langle Dump the array info for internal font number k 1498 $\rangle \equiv$

```

begin  $\text{dump\_qqqq}(\text{font\_check}[k]);$   $\text{dump\_int}(\text{font\_size}[k]);$   $\text{dump\_int}(\text{font\_dsize}[k]);$ 
 $\text{dump\_int}(\text{font\_params}[k]);$ 
 $\text{dump\_int}(\text{hyphen\_char}[k]);$   $\text{dump\_int}(\text{skew\_char}[k]);$ 
 $\text{dump\_int}(\text{font\_name}[k]);$   $\text{dump\_int}(\text{font\_area}[k]);$ 
 $\text{dump\_int}(\text{font\_bc}[k]);$   $\text{dump\_int}(\text{font\_ec}[k]);$ 
 $\text{dump\_int}(\text{char\_base}[k]);$   $\text{dump\_int}(\text{width\_base}[k]);$   $\text{dump\_int}(\text{height\_base}[k]);$ 
 $\text{dump\_int}(\text{depth\_base}[k]);$   $\text{dump\_int}(\text{italic\_base}[k]);$   $\text{dump\_int}(\text{lig\_kern\_base}[k]);$ 
 $\text{dump\_int}(\text{kern\_base}[k]);$   $\text{dump\_int}(\text{exten\_base}[k]);$   $\text{dump\_int}(\text{param\_base}[k]);$ 
 $\text{dump\_int}(\text{font\_glue}[k]);$ 
 $\text{dump\_int}(\text{bchar\_label}[k]);$   $\text{dump\_int}(\text{font\_bchar}[k]);$   $\text{dump\_int}(\text{font\_false\_bchar}[k]);$ 
 $\text{print\_nl}(\text{"\font"});$   $\text{print\_esc}(\text{font\_id\_text}(k));$   $\text{print\_char}(\text{"="});$ 
 $\text{print\_file\_name}(\text{font\_name}[k], \text{font\_area}[k], \text{""});$ 
if  $\text{font\_size}[k] \neq \text{font\_dsize}[k]$  then
  begin  $\text{print}(\text{"\_at\_"});$   $\text{print\_scaled}(\text{font\_size}[k]);$   $\text{print}(\text{"pt"});$ 
  end;
end

```

This code is used in section 1496.

1499. \langle Undump the array info for internal font number k 1499 $\rangle \equiv$

```

begin undump_qqqq(font_check[k]);
undump_int(font_size[k]); undump_int(font_dsize[k]);
undump(min_halfword)(max_halfword)(font_params[k]);
undump_int(hyphen_char[k]); undump_int(skew_char[k]);
undump(0)(str_ptr)(font_name[k]); undump(0)(str_ptr)(font_area[k]);
undump(0)(255)(font_bc[k]); undump(0)(255)(font_ec[k]);
undump_int(char_base[k]); undump_int(width_base[k]); undump_int(height_base[k]);
undump_int(depth_base[k]); undump_int(italic_base[k]); undump_int(lig_kern_base[k]);
undump_int(kern_base[k]); undump_int(exten_base[k]); undump_int(param_base[k]);
undump(min_halfword)(lo_mem_max)(font_glue[k]);
undump(0)(fmem_ptr - 1)(bchar_label[k]); undump(min_quarterword)(non_char)(font_bchar[k]);
undump(min_quarterword)(non_char)(font_false_bchar[k]);
end

```

This code is used in section 1497.

1500. \langle Dump the hyphenation tables 1500 $\rangle \equiv$

```

dump_int(hyph_count);
for  $k \leftarrow 0$  to hyph_size do
  if hyph_word[k]  $\neq 0$  then
    begin dump_int(k); dump_int(hyph_word[k]); dump_int(hyph_list[k]);
    end;
  print_ln; print_int(hyph_count); print("_hyphenation_exception");
if hyph_count  $\neq 1$  then print_char("s");
if trie_not_ready then init_trie;
dump_int(trie_max); dump_int(hyph_start);
for  $k \leftarrow 0$  to trie_max do dump_hh(trie[k]);
dump_int(trie_op_ptr);
for  $k \leftarrow 1$  to trie_op_ptr do
  begin dump_int(hyf_distance[k]); dump_int(hyf_num[k]); dump_int(hyf_next[k]);
  end;
print_nl("Hyphenation_trie_of_length"); print_int(trie_max); print("_has");
print_int(trie_op_ptr); print("_op");
if trie_op_ptr  $\neq 1$  then print_char("s");
print("_out_of"); print_int(trie_op_size);
for  $k \leftarrow 255$  downto 0 do
  if trie_used[k]  $>$  min_quarterword then
    begin print_nl("_"); print_int(qo(trie_used[k])); print("_for_language"); print_int(k);
    dump_int(k); dump_int(qo(trie_used[k]));
    end

```

This code is used in section 1478.

1501. Only “nonempty” parts of *op_start* need to be restored.

```

< Undump the hyphenation tables 1501 > ≡
  undump(0)(hyph_size)(hyph_count);
  for k ← 1 to hyph_count do
    begin undump(0)(hyph_size)(j); undump(0)(str_ptr)(hyph_word[j]);
    undump(min_halfword)(max_halfword)(hyph_list[j]);
    end;
  undump_size(0)(trie_size)(`trie_size`)(j); init trie_max ← j; tini undump(0)(j)(hyph_start);
  for k ← 0 to j do undump_hh(trie[k]);
  undump_size(0)(trie_op_size)(`trie_op_size`)(j); init trie_op_ptr ← j; tini
  for k ← 1 to j do
    begin undump(0)(63)(hyf_distance[k]); { a small_number }
    undump(0)(63)(hyf_num[k]); undump(min_quarterword)(max_quarterword)(hyf_next[k]);
    end;
  init for k ← 0 to 255 do trie_used[k] ← min_quarterword;
  tini
  k ← 256;
  while j > 0 do
    begin undump(0)(k - 1)(k); undump(1)(j)(x); init trie_used[k] ← qi(x); tini
    j ← j - x; op_start[k] ← qo(j);
    end;
  init trie_not_ready ← false tini

```

This code is used in section 1479.

1502. Store some of the pdftex data structures in the format. The idea here is to ensure that any data structures referenced from pdftex-specific whatsit nodes are retained. For the sake of simplicity and speed, all the filled parts of *pdf_mem* and *obj_tab* are retained, in the present implementation. We also retain three of the linked lists that start from *head_tab*, so that it is possible to, say, load an image in the INITEX run and then reference it in a VIRTEX run that uses the dumped format.

```

< Dump pdftex data 1502 > ≡
  begin dumpimagemeta; { the image information array }
  dump_int(pdf_mem_size); dump_int(pdf_mem_ptr);
  for k ← 1 to pdf_mem_ptr - 1 do
    begin dump_int(pdf_mem[k]);
    end;
  print_ln; print_int(pdf_mem_ptr - 1); print("_words_of_pdfTeX_memory"); dump_int(obj_tab_size);
  dump_int(obj_ptr); dump_int(sys_obj_ptr);
  for k ← 1 to sys_obj_ptr do
    begin dump_int(obj_tab[k].int0); dump_int(obj_tab[k].int1); dump_int(obj_tab[k].int3);
    dump_int(obj_tab[k].int4);
    end;
  print_ln; print_int(sys_obj_ptr); print("_indirect_objects"); dump_int(pdf_obj_count);
  dump_int(pdf_xform_count); dump_int(pdf_ximage_count); dump_int(head_tab[obj_type_obj]);
  dump_int(head_tab[obj_type_xform]); dump_int(head_tab[obj_type_ximage]); dump_int(pdf_last_obj);
  dump_int(pdf_last_xform); dump_int(pdf_last_ximage); dumptounicode;
  end

```

This code is used in section 1478.

1503. And restoring the pdfTeX data structures from the format. The two function arguments to *undumpimagemeta* have been restored already in an earlier module.

```

⟨ Undump pdfTeX data 1503 ⟩ ≡
  begin undumpimagemeta(pdf_major_version, pdf_minor_version, pdf_inclusion_errorlevel);
    { the image information array }
    undump_int(pdf_mem_size); pdf_mem ← xrealloc_array(pdf_mem, integer, pdf_mem_size);
    undump_int(pdf_mem_ptr);
    for k ← 1 to pdf_mem_ptr - 1 do
      begin undump_int(pdf_mem[k]);
    end;
    undump_int(obj_tab_size); undump_int(obj_ptr); undump_int(sys_obj_ptr);
    for k ← 1 to sys_obj_ptr do
      begin undump_int(obj_tab[k].int0); undump_int(obj_tab[k].int1); obj_tab[k].int2 ← -1;
        undump_int(obj_tab[k].int3); undump_int(obj_tab[k].int4);
      end;
    undump_int(pdf_obj_count); undump_int(pdf_xform_count); undump_int(pdf_ximage_count);
    undump_int(head_tab[obj_type_obj]); undump_int(head_tab[obj_type_xform]);
    undump_int(head_tab[obj_type_ximage]); undump_int(pdf_last_obj); undump_int(pdf_last_xform);
    undump_int(pdf_last_ximage); undumptounicode;
  end

```

This code is used in section 1479.

1504. We have already printed a lot of statistics, so we set *tracing_stats* ← 0 to prevent them from appearing again.

```

⟨ Dump a couple more things and the closing check word 1504 ⟩ ≡
  dump_int(interaction); dump_int(format_ident); dump_int(69069); tracing_stats ← 0

```

This code is used in section 1478.

```

1505. ⟨ Undump a couple more things and the closing check word 1505 ⟩ ≡
  undump(batch_mode)(error_stop_mode)(interaction); undump(0)(str_ptr)(format_ident); undump_int(x);
  if (x ≠ 69069) ∨ eof(fmt_file) then goto bad_fmt

```

This code is used in section 1479.

1506. ⟨ Create the *format_ident*, open the format file, and inform the user that dumping has begun 1506 ⟩ ≡

```

  selector ← new_string; print("␣(preloaded␣format="); print(job_name); print_char("␣");
  print_int(year); print_char("."); print_int(month); print_char("."); print_int(day); print_char(")");
  if interaction = batch_mode then selector ← log_only
  else selector ← term_and_log;
  str_room(1); format_ident ← make_string; pack_job_name(format_extension);
  while ¬w_open_out(fmt_file) do prompt_file_name("format␣file␣name", format_extension);
  print_nl("Beginning␣to␣dump␣on␣file␣"); slow_print(w_make_name_string(fmt_file)); flush_string;
  print_nl(""); slow_print(format_ident)

```

This code is used in section 1478.

```

1507. ⟨ Close the format file 1507 ⟩ ≡
  w_close(fmt_file)

```

This code is used in section 1478.

1508. The main program. This is it: the part of TeX that executes all those procedures we have written.

Well—almost. Let’s leave space for a few more routines that we may have forgotten.

⟨ Last-minute procedures 1511 ⟩

1509. We have noted that there are two versions of TeX82. One, called INITEX, has to be run first; it initializes everything from scratch, without reading a format file, and it has the capability of dumping a format file. The other one is called ‘VIRTEX’; it is a “virgin” program that needs to input a format file in order to get started. VIRTEX typically has more memory capacity than INITEX, because it does not need the space consumed by the auxiliary hyphenation tables and the numerous calls on *primitive*, etc.

The VIRTEX program cannot read a format file instantaneously, of course; the best implementations therefore allow for production versions of TeX that not only avoid the loading routine for Pascal object code, they also have a format file pre-loaded. This is impossible to do if we stick to standard Pascal; but there is a simple way to fool many systems into avoiding the initialization, as follows: (1) We declare a global integer variable called *ready_already*. The probability is negligible that this variable holds any particular value like 314159 when VIRTEX is first loaded. (2) After we have read in a format file and initialized everything, we set *ready_already* ← 314159. (3) Soon VIRTEX will print ‘*’, waiting for more input; and at this point we interrupt the program and save its core image in some form that the operating system can reload speedily. (4) When that core image is activated, the program starts again at the beginning; but now *ready_already* = 314159 and all the other global variables have their initial values too. The former chastity has vanished!

In other words, if we allow ourselves to test the condition *ready_already* = 314159, before *ready_already* has been assigned a value, we can avoid the lengthy initialization. Dirty tricks rarely pay off so handsomely.

On systems that allow such preloading, the standard program called TeX should be the one that has **plain** format preloaded, since that agrees with *The TeXbook*. Other versions, e.g., AmSTeX, should also be provided for commonly used formats.

⟨ Global variables 13 ⟩ +≡

ready_already: integer; { a sacrifice of purity for economy }

1510. Now this is really it: T_EX starts and ends here.

The initial test involving *ready_already* should be deleted if the Pascal runtime system is smart enough to detect such a “mistake.”

```

begin    { start_here }
history ← fatal_error_stop; { in case we quit during initialization }
t_open_out; { open the terminal for output }
if ready_already = 314159 then goto start_of_TEX;
⟨ Check the “constant” values for consistency 14 ⟩
if bad > 0 then
    begin wterm_ln(‘Ouch---my_internal_constants_have_been_clobbered!’, ‘---case_’, bad : 1);
    goto final_end;
    end;
initialize; { set global variables to their starting values }
init if ¬get_strings_started then goto final_end;
init_prim; { call primitive for each primitive }
init_str_ptr ← str_ptr; init_pool_ptr ← pool_ptr; fix_date_and_time;
tini
    ready_already ← 314159;
start_of_TEX: ⟨ Initialize the output routines 55 ⟩;
    ⟨ Get the first line of input and prepare to start 1515 ⟩;
    history ← spotless; { ready to go! }
    main_control; { come to life }
    final_cleanup; { prepare for death }
end_of_TEX: close_files_and_terminate;
final_end: ready_already ← 0;
end.

```

1511. Here we do whatever is needed to complete TeX’s job gracefully on the local operating system. The code here might come into play after a fatal error; it must therefore consist entirely of “safe” operations that cannot produce error messages. For example, it would be a mistake to call *str_room* or *make_string* at this time, because a call on *overflow* might lead to an infinite loop. (Actually there’s one way to get error messages, via *prepare_mag*; but that can’t cause infinite recursion.)

If *final_cleanup* is bypassed, this program doesn’t bother to close the input files that may still be open.

⟨Last-minute procedures 1511⟩ ≡

procedure *close_files_and_terminate*;

label *done, done1*;

var *a, b, c, i, j, k, l*: *integer*; { all-purpose index }

is_root: *boolean*; { *pdf_last_pages* is root of Pages tree? }

is_names: *boolean*; { flag for name tree output: is it Names or Kids? }

root, outlines, threads, names_tree, dests: *integer*; *xref_offset_width, names_head, names_tail*: *integer*;

begin ⟨Finish the extensions 1623⟩;

new_line_char ← −1;

stat if *tracing_stats* > 0 **then** ⟨Output statistics about this job 1512⟩; **tats**

wake_up_terminal;

if ¬*fixed_pdfoutput_set* **then** *fix_pdfoutput*;

if *fixed_pdfoutput* > 0 **then**

begin if *history* = *fatal_error_stop* **then**

begin *remove_pdffile*;

print_err("␣==>Fatal␣error␣occurred,␣no␣output␣PDF␣file␣produced!")

end

else begin ⟨Finish the PDF file 794⟩;

if *log_opened* **then**

begin *wlog_cr*; *wlog_ln*(`PDF␣statistics:`,); *wlog_ln*(`␣`, *obj_ptr* : 1,
 `␣PDF␣objects␣out␣of␣`, *obj_tab_size* : 1, `␣(max.␣`, *sup_obj_tab_size* : 1, `)`);

if *pdf_os_cntr* > 0 **then**

begin *wlog*(`␣`, ((*pdf_os_cntr* − 1) * *pdf_os_max_objs* + *pdf_os_objidx* + 1) : 1,

 `␣compressed␣objects␣within␣`, *pdf_os_cntr* : 1, `␣object␣stream`);

if *pdf_os_cntr* > 1 **then** *wlog*(`s`);

wlog_cr;

end;

wlog_ln(`␣`, *pdf_dest_names_ptr* : 1, `␣named␣destinations␣out␣of␣`, *dest_names_size* : 1,

 `␣(max.␣`, *sup_dest_names_size* : 1, `)`);

wlog_ln(`␣`, *pdf_mem_ptr* : 1, `␣words␣of␣extra␣memory␣for␣PDF␣output␣out␣of␣`,

pdf_mem_size : 1, `␣(max.␣`, *sup_pdf_mem_size* : 1, `)`);

end;

end;

end

else begin ⟨Finish the DVI file 670⟩;

end;

if *log_opened* **then**

begin *wlog_cr*; *a_close*(*log_file*); *selector* ← *selector* − 2;

if *selector* = *term_only* **then**

begin *print_nl*("Transcript␣written␣on␣"); *slow_print*(*log_name*); *print_char*(".");

end;

end;

end;

See also sections 1513, 1514, and 1516.

This code is used in section 1508.

1512. The present section goes directly to the log file instead of using *print* commands, because there's no need for these strings to take up *str-pool* memory when a non-**stat** version of TeX is being used.

⟨Output statistics about this job 1512⟩ ≡

```

if log_opened then
  begin wlog_ln(`_`); wlog_ln(`Here_is_how_much_of_TeX`s_memory`, `you_used:`);
  wlog(`_`, str_ptr - init_str_ptr : 1, `_string`);
  if str_ptr ≠ init_str_ptr + 1 then wlog(`s`);
  wlog_ln(`_out_of_`, max_strings - init_str_ptr : 1);
  wlog_ln(`_`, pool_ptr - init_pool_ptr : 1, `_string_characters_out_of_`, pool_size - init_pool_ptr : 1);
  wlog_ln(`_`, lo_mem_max - mem_min + mem_end - hi_mem_min + 2 : 1,
    `_words_of_memory_out_of_`, mem_end + 1 - mem_min : 1);
  wlog_ln(`_`, cs_count : 1, `_multiletter_control_sequences_out_of_`, hash_size : 1);
  wlog(`_`, fmem_ptr : 1, `_words_of_font_info_for_`, font_ptr - font_base : 1, `_font`);
  if font_ptr ≠ font_base + 1 then wlog(`s`);
  wlog_ln(`_`, out_of_`, font_mem_size : 1, `_for_`, font_max - font_base : 1);
  wlog(`_`, hyph_count : 1, `_hyphenation_exception`);
  if hyph_count ≠ 1 then wlog(`s`);
  wlog_ln(`_out_of_`, hyph_size : 1);
  wlog_ln(`_`, max_in_stack : 1, `_i`, max_nest_stack : 1, `_n`, max_param_stack : 1, `_p`,
    max_buf_stack + 1 : 1, `_b`, max_save_stack + 6 : 1, `_s_stack_positions_out_of_`,
    stack_size : 1, `_i`, nest_size : 1, `_n`, param_size : 1, `_p`, buf_size : 1, `_b`, save_size : 1, `_s`);
  end

```

This code is used in section 1511.

1513. We get to the *final_cleanup* routine when `\end` or `\dump` has been scanned and *its_all_over*.

⟨ Last-minute procedures 1511 ⟩ +≡

```

procedure final_cleanup;
  label exit;
  var c: small_number; { 0 for \end, 1 for \dump }
  begin c ← cur_chr;
  if c ≠ 1 then new_line_char ← -1;
  if job_name = 0 then open_log_file;
  while input_ptr > 0 do
    if state = token_list then end_token_list else end_file_reading;
  while open_parens > 0 do
    begin print("␣"); decr(open_parens);
    end;
  if cur_level > level_one then
    begin print_nl(""); print_esc("end␣occurred␣"); print("inside␣a␣group␣at␣level␣");
    print_int(cur_level - level_one); print_char("");
    if eTeX_ex then show_save_groups;
    end;
  while cond_ptr ≠ null do
    begin print_nl(""); print_esc("end␣occurred␣"); print("when␣"); print_cmd_chr(if_test, cur_if);
    if if_line ≠ 0 then
      begin print("␣on␣line␣"); print_int(if_line);
      end;
    print("␣was␣incomplete"); if_line ← if_line_field(cond_ptr); cur_if ← subtype(cond_ptr);
    temp_ptr ← cond_ptr; cond_ptr ← link(cond_ptr); free_node(temp_ptr, if_node_size);
    end;
  if history ≠ spotless then
    if ((history = warning_issued) ∨ (interaction < error_stop_mode)) then
      if selector = term_and_log then
        begin selector ← term_only;
        print_nl("(see␣the␣transcript␣file␣for␣additional␣information)");
        selector ← term_and_log;
        end;
  if c = 1 then
    begin init for c ← top_mark_code to split_bot_mark_code do
      if cur_mark[c] ≠ null then delete_token_ref(cur_mark[c]);
    if sa_mark ≠ null then
      if do_marks(destroy_marks, 0, sa_mark) then sa_mark ← null;
    for c ← last_box_code to vsplit_code do flush_node_list(disc_ptr[c]);
    if last_glue ≠ max_halfword then delete_glue_ref(last_glue);
    store_fmt_file; return; tini
    print_nl("(␣dump␣is␣performed␣only␣by␣INITEX)"); return;
    end;
  exit: end;

```

1514. ⟨ Last-minute procedures 1511 ⟩ +≡

```

init procedure init_prim; { initialize all the primitives }
begin no_new_control_sequence ← false; first ← 0;
⟨ Put each of TeX's primitives into the hash table 244 ⟩;
no_new_control_sequence ← true;
end;
tini

```

1515. When we begin the following code, TeX's tables may still contain garbage; the strings might not even be present. Thus we must proceed cautiously to get bootstrapped in.

But when we finish this part of the program, TeX is ready to call on the *main_control* routine to do its work.

```

⟨ Get the first line of input and prepare to start 1515 ⟩ ≡
  begin ⟨ Initialize the input routines 353 ⟩;
  ⟨ Enable ε-TeX, if requested 1645 ⟩
  if (format_ident = 0) ∨ (buffer[loc] = "&") then
    begin if format_ident ≠ 0 then initialize; { erase preloaded format }
    if ¬open_fmt_file then goto final_end;
    if ¬load_fmt_file then
      begin w_close(fmt_file); goto final_end;
      end;
    w_close(fmt_file);
    while (loc < limit) ∧ (buffer[loc] = " ") do incr(loc);
    end;
  if (pdf_output_option ≠ 0) then pdf_output ← pdf_output_value;
  if (pdf_draftmode_option ≠ 0) then pdf_draftmode ← pdf_draftmode_value;
  pdf_init_map_file('pdftex.map');
  if eTeX_ex then wterm_ln('entering extended mode');
  if end_line_char_inactive then decr(limit)
  else buffer[limit] ← end_line_char;
  fix_date_and_time;
  random_seed ← (microseconds * 1000) + (epochseconds mod 1000000);
  init_randoms(random_seed);
  ⟨ Compute the magic offset 939 ⟩;
  ⟨ Initialize the print selector based on interaction 75 ⟩;
  if (loc < limit) ∧ (cat_code(buffer[loc]) ≠ escape) then start_input; { \input assumed }
  end

```

This code is used in section 1510.

1516. Debugging. Once T_EX is working, you should be able to diagnose most errors with the `\show` commands and other diagnostic features. But for the initial stages of debugging, and for the revelation of really deep mysteries, you can compile T_EX with a few more aids, including the Pascal runtime checks and its debugger. An additional routine called *debug_help* will also come into play when you type ‘D’ after an error message; *debug_help* also occurs just before a fatal error causes T_EX to succumb.

The interface to *debug_help* is primitive, but it is good enough when used with a Pascal debugger that allows you to set breakpoints and to read variables and change their values. After getting the prompt ‘debug #’, you type either a negative number (this exits *debug_help*), or zero (this goes to a location where you can set a breakpoint, thereby entering into dialog with the Pascal debugger), or a positive number *m* followed by an argument *n*. The meaning of *m* and *n* will be clear from the program below. (If *m* = 13, there is an additional argument, *l*.)

```

define breakpoint = 888 { place where a breakpoint is desirable }
⟨Last-minute procedures 1511⟩ +≡
debug procedure debug_help; { routine to display various things }
label breakpoint, exit;
var k, l, m, n: integer;
begin clear_terminal;
loop
  begin wake_up_terminal; print_nl("debug_#_(-1_to_exit):"); update_terminal; read(term_in, m);
  if m < 0 then return
  else if m = 0 then
    begin goto breakpoint;
    { go to every declared label at least once }
    breakpoint: m ← 0; @{‘BREAKPOINT’@}
    end
  else begin read(term_in, n);
    case m of
      ⟨Numbered cases for debug_help 1517⟩
    othercases print("?")
    endcases;
  end;
end;
exit: end;
gubed

```

1517. \langle Numbered cases for *debug_help* 1517 $\rangle \equiv$

```

1: print_word(mem[n]);  { display mem[n] in all forms }
2: print_int(info(n));
3: print_int(link(n));
4: print_word(eqtb[n]);
5: print_word(font_info[n]);
6: print_word(save_stack[n]);
7: show_box(n);  { show a box, abbreviated by show_box_depth and show_box_breadth }
8: begin breadth_max  $\leftarrow$  10000; depth_threshold  $\leftarrow$  pool_size - pool_ptr - 10; show_node_list(n);
    { show a box in its entirety }
    end;
9: show_token_list(n, null, 1000);
10: slow_print(n);
11: check_mem(n > 0);  { check wellformedness; print new busy locations if n > 0 }
12: search_mem(n);  { look for pointers to n }
13: begin read(term_in, l); print_cmd_chr(n, l);
    end;
14: for k  $\leftarrow$  0 to n do print(buffer[k]);
15: begin font_in_short_display  $\leftarrow$  null_font; short_display(n);
    end;
16: panicking  $\leftarrow$   $\neg$ panicking;

```

This code is used in section 1516.

1518. Extensions. The program above includes a bunch of “hooks” that allow further capabilities to be added without upsetting TeX’s basic structure. Most of these hooks are concerned with “whatsit” nodes, which are intended to be used for special purposes; whenever a new extension to TeX involves a new kind of whatsit node, a corresponding change needs to be made to the routines below that deal with such nodes, but it will usually be unnecessary to make many changes to the other parts of this program.

In order to demonstrate how extensions can be made, we shall treat ‘\write’, ‘\openout’, ‘\closeout’, ‘\immediate’, ‘\special’, and ‘\setlanguage’ as if they were extensions. These commands are actually primitives of TeX, and they should appear in all implementations of the system; but let’s try to imagine that they aren’t. Then the program below illustrates how a person could add them.

Sometimes, of course, an extension will require changes to TeX itself; no system of hooks could be complete enough for all conceivable extensions. The features associated with ‘\write’ are almost all confined to the following paragraphs, but there are small parts of the *print_ln* and *print_char* procedures that were introduced specifically to \write characters. Furthermore one of the token lists recognized by the scanner is a *write_text*; and there are a few other miscellaneous places where we have already provided for some aspect of \write. The goal of a TeX extender should be to minimize alterations to the standard parts of the program, and to avoid them completely if possible. He or she should also be quite sure that there’s no easy way to accomplish the desired goals with the standard features that TeX already has. “Think thrice before extending,” because that may save a lot of work, and it will also keep incompatible extensions of TeX from proliferating.

1519. First let’s consider the format of whatsit nodes that are used to represent the data associated with \write and its relatives. Recall that a whatsit has *type* = *whatsit_node*, and the *subtype* is supposed to distinguish different kinds of whatsits. Each node occupies two or more words; the exact number is immaterial, as long as it is readily determined from the *subtype* or other data.

We shall introduce five *subtype* values here, corresponding to the control sequences \openout, \write, \closeout, \special, and \setlanguage. The second word of I/O whatsits has a *write_stream* field that identifies the write-stream number (0 to 15, or 16 for out-of-range and positive, or 17 for out-of-range and negative). In the case of \write and \special, there is also a field that points to the reference count of a token list that should be sent. In the case of \openout, we need three words and three auxiliary subfields to hold the string numbers for name, area, and extension.

```

define write_node_size = 2 { number of words in a write/whatsit node }
define open_node_size = 3 { number of words in an open/whatsit node }
define open_node = 0 { subtype in whatsits that represent files to \openout }
define write_node = 1 { subtype in whatsits that represent things to \write }
define close_node = 2 { subtype in whatsits that represent streams to \closeout }
define special_node = 3 { subtype in whatsits that represent \special things }
define language_node = 4 { subtype in whatsits that change the current language }
define what_lang(#) ≡ link(# + 1) { language number, in the range 0 .. 255 }
define what_lhm(#) ≡ type(# + 1) { minimum left fragment, in the range 1 .. 63 }
define what_rhm(#) ≡ subtype(# + 1) { minimum right fragment, in the range 1 .. 63 }
define write_tokens(#) ≡ link(# + 1) { reference count of token list to write }
define write_stream(#) ≡ info(# + 1) { stream number (0 to 17) }
define open_name(#) ≡ link(# + 1) { string number of file name to open }
define open_area(#) ≡ info(# + 2) { string number of file area for open_name }
define open_ext(#) ≡ link(# + 2) { string number of file extension for open_name }

```

1520. The sixteen possible `\write` streams are represented by the *write_file* array. The *j*th file is open if and only if *write_open*[*j*] = *true*. The last two streams are special; *write_open*[16] represents a stream number greater than 15, while *write_open*[17] represents a negative stream number, and both of these variables are always *false*.

⟨ Global variables 13 ⟩ +≡

write_file: **array** [0 .. 15] **of** *alpha_file*;

write_open: **array** [0 .. 17] **of** *boolean*;

1521. ⟨ Set initial values of key variables 21 ⟩ +≡

for *k* ← 0 **to** 17 **do** *write_open*[*k*] ← *false*;

1522. Extensions might introduce new command codes; but it's best to use *extension* with a modifier, whenever possible, so that *main_control* stays the same.

```

define immediate_code = 4 { command modifier for \immediate }
define set_language_code = 5 { command modifier for \setlanguage }
define pdftex_first_extension_code = 6
define pdf_literal_node ≡ pdftex_first_extension_code + 0
define pdf_obj_code ≡ pdftex_first_extension_code + 1
define pdf_refobj_node ≡ pdftex_first_extension_code + 2
define pdf_xform_code ≡ pdftex_first_extension_code + 3
define pdf_refxform_node ≡ pdftex_first_extension_code + 4
define pdf_ximage_code ≡ pdftex_first_extension_code + 5
define pdf_refximage_node ≡ pdftex_first_extension_code + 6
define pdf_annot_node ≡ pdftex_first_extension_code + 7
define pdf_start_link_node ≡ pdftex_first_extension_code + 8
define pdf_end_link_node ≡ pdftex_first_extension_code + 9
define pdf_outline_code ≡ pdftex_first_extension_code + 10
define pdf_dest_node ≡ pdftex_first_extension_code + 11
define pdf_thread_node ≡ pdftex_first_extension_code + 12
define pdf_start_thread_node ≡ pdftex_first_extension_code + 13
define pdf_end_thread_node ≡ pdftex_first_extension_code + 14
define pdf_save_pos_node ≡ pdftex_first_extension_code + 15
define pdf_info_code ≡ pdftex_first_extension_code + 16
define pdf_catalog_code ≡ pdftex_first_extension_code + 17
define pdf_names_code ≡ pdftex_first_extension_code + 18
define pdf_font_attr_code ≡ pdftex_first_extension_code + 19
define pdf_include_chars_code ≡ pdftex_first_extension_code + 20
define pdf_map_file_code ≡ pdftex_first_extension_code + 21
define pdf_map_line_code ≡ pdftex_first_extension_code + 22
define pdf_trailer_code ≡ pdftex_first_extension_code + 23
define pdf_trailer_id_code ≡ pdftex_first_extension_code + 24
define reset_timer_code ≡ pdftex_first_extension_code + 25
define pdf_font_expand_code ≡ pdftex_first_extension_code + 26
define set_random_seed_code ≡ pdftex_first_extension_code + 27
define pdf_snap_ref_point_node ≡ pdftex_first_extension_code + 28
define pdf_snap_node ≡ pdftex_first_extension_code + 29
define pdf_snap_node_comp_node ≡ pdftex_first_extension_code + 30
define pdf_glyph_to_unicode_code ≡ pdftex_first_extension_code + 31
define pdf_colorstack_node ≡ pdftex_first_extension_code + 32
define pdf_setmatrix_node ≡ pdftex_first_extension_code + 33
define pdf_save_node ≡ pdftex_first_extension_code + 34
define pdf_restore_node ≡ pdftex_first_extension_code + 35
define pdf_nobuiltin_tounicode_code ≡ pdftex_first_extension_code + 36
define pdf_interword_space_on_node ≡ pdftex_first_extension_code + 37
define pdf_interword_space_off_node ≡ pdftex_first_extension_code + 38
define pdf_fake_space_node ≡ pdftex_first_extension_code + 39
define pdf_running_link_off_node ≡ pdftex_first_extension_code + 40
define pdf_running_link_on_node ≡ pdftex_first_extension_code + 41
define pdftex_last_extension_code ≡ pdftex_first_extension_code + 41

```

(Put each of TeX's primitives into the hash table 244) +=

```

primitive("openout", extension, open_node);
primitive("write", extension, write_node); write_loc ← cur_val;
primitive("closeout", extension, close_node);

```

```

primitive("special", extension, special_node);
primitive("immediate", extension, immediate_code);
primitive("setlanguage", extension, set_language_code);
primitive("pdfliteral", extension, pdf_literal_node);
primitive("pdfcolorstack", extension, pdf_colorstack_node);
primitive("pdfsetmatrix", extension, pdf_setmatrix_node);
primitive("pdfsave", extension, pdf_save_node);
primitive("pdfrestore", extension, pdf_restore_node);
primitive("pdfobj", extension, pdf_obj_code);
primitive("pdfrefobj", extension, pdf_refobj_node);
primitive("pdfxform", extension, pdf_xform_code);
primitive("pdfrefxform", extension, pdf_refxform_node);
primitive("pdfximage", extension, pdf_ximage_code);
primitive("pdfrefximage", extension, pdf_refximage_node);
primitive("pdfannot", extension, pdf_annot_node);
primitive("pdfstartlink", extension, pdf_start_link_node);
primitive("pdfendlink", extension, pdf_end_link_node);
primitive("pdfoutline", extension, pdf_outline_code);
primitive("pdfdest", extension, pdf_dest_node);
primitive("pdfthread", extension, pdf_thread_node);
primitive("pdfstartthread", extension, pdf_start_thread_node);
primitive("pdfendthread", extension, pdf_end_thread_node);
primitive("pdfsavepos", extension, pdf_save_pos_node);
primitive("pdfsnaprefpoint", extension, pdf_snap_ref_point_node);
primitive("pdfsnapy", extension, pdf_snap_y_node);
primitive("pdfsnapycomp", extension, pdf_snap_y_comp_node);
primitive("pdfinfo", extension, pdf_info_code);
primitive("pdfcatalog", extension, pdf_catalog_code);
primitive("pdfnames", extension, pdf_names_code);
primitive("pdfincludechars", extension, pdf_include_chars_code);
primitive("pdffontattr", extension, pdf_font_attr_code);
primitive("pdfmapfile", extension, pdf_map_file_code);
primitive("pdfmapline", extension, pdf_map_line_code);
primitive("pdftrailer", extension, pdf_trailer_code);
primitive("pdftrailerid", extension, pdf_trailer_id_code);
primitive("pdfresettimer", extension, reset_timer_code);
primitive("pdfsetrandomseed", extension, set_random_seed_code);
primitive("pdffontexpand", extension, pdf_font_expand_code);
primitive("pdfglyptounicode", extension, pdf_glyph_to_unicode_code);
primitive("pdfnobuiltintounicode", extension, pdf_nobuiltin_tounicode_code);
primitive("pdfinterwordspaceon", extension, pdf_interword_space_on_node);
primitive("pdfinterwordspaceoff", extension, pdf_interword_space_off_node);
primitive("pdffakespace", extension, pdf_fake_space_node);
primitive("pdfrunninglinkoff", extension, pdf_running_link_off_node);
primitive("pdfrunninglinkon", extension, pdf_running_link_on_node);

```

1523. The variable *write_loc* just introduced is used to provide an appropriate error message in case of “runaway” write texts.

{ Global variables 13 } +≡

write_loc: pointer; { eqtb address of \write }

1524. \langle Cases of *print_cmd_chr* for symbolic printing of primitives 245 $\rangle + \equiv$
extension: **case** *chr_code* **of**

```

  open_node: print_esc("openout");
  write_node: print_esc("write");
  close_node: print_esc("closeout");
  special_node: print_esc("special");
  immediate_code: print_esc("immediate");
  set_language_code: print_esc("setlanguage");
  pdf_annot_node: print_esc("pdfannot");
  pdf_catalog_code: print_esc("pdfcatalog");
  pdf_dest_node: print_esc("pdfdest");
  pdf_end_link_node: print_esc("pdfendlink");
  pdf_end_thread_node: print_esc("pdfendthread");
  pdf_font_attr_code: print_esc("pdffontattr");
  pdf_font_expand_code: print_esc("pdffontexpand");
  pdf_include_chars_code: print_esc("pdfincludechars");
  pdf_info_code: print_esc("pdfinfo");
  pdf_literal_node: print_esc("pdfliteral");
  pdf_colorstack_node: print_esc("pdfcolorstack");
  pdf_setmatrix_node: print_esc("pdfsetmatrix");
  pdf_save_node: print_esc("pdfsave");
  pdf_restore_node: print_esc("pdfrestore");
  pdf_map_file_code: print_esc("pdfmapfile");
  pdf_map_line_code: print_esc("pdfmapline");
  pdf_names_code: print_esc("pdfnames");
  pdf_obj_code: print_esc("pdfobj");
  pdf_outline_code: print_esc("pdfoutline");
  pdf_refobj_node: print_esc("pdfrefobj");
  pdf_refxform_node: print_esc("pdfrefxform");
  pdf_refximage_node: print_esc("pdfrefximage");
  pdf_save_pos_node: print_esc("pdfsavepos");
  pdf_snap_ref_point_node: print_esc("pdfsnaprefpoint");
  pdf_snapyp_comp_node: print_esc("pdfsnapypcomp");
  pdf_snapyp_node: print_esc("pdfsnapyp");
  pdf_start_link_node: print_esc("pdfstartlink");
  pdf_start_thread_node: print_esc("pdfstartthread");
  pdf_thread_node: print_esc("pdfthread");
  pdf_trailer_code: print_esc("pdftrailer");
  pdf_trailer_id_code: print_esc("pdftrailerid");
  pdf_xform_code: print_esc("pdfxform");
  pdf_ximage_code: print_esc("pdfximage");
  reset_timer_code: print_esc("pdfresettimer");
  set_random_seed_code: print_esc("pdfsetrandomseed");
  pdf_nobuiltin_tounicode_code: print_esc("pdfnobuiltintounicode");
  pdf_glyph_to_unicode_code: print_esc("pdfglyphtounicode");
  pdf_interword_space_on_node: print_esc("pdfinterwordspaceon");
  pdf_interword_space_off_node: print_esc("pdfinterwordspaceoff");
  pdf_fake_space_node: print_esc("pdffakespace");
  pdf_running_link_off_node: print_esc("pdfrunninglinkoff");
  pdf_running_link_on_node: print_esc("pdfrunninglinkon");
othercases print("[unknown_extension!]")
endcases;

```

1525. When an *extension* command occurs in *main_control*, in any mode, the *do_extension* routine is called.

⟨ Cases of *main_control* that are for extensions to T_EX 1525 ⟩ ≡
any_mode(extension): do_extension;

This code is used in section 1221.

1526. \langle Declare action procedures for use by *main_control* 1219 $\rangle + \equiv$
 \langle Declare procedures needed in *do_extension* 1527 \rangle

procedure *do_extension*;

var *i, j, k*: *integer*; { all-purpose integers }
p, q, r: *pointer*; { all-purpose pointers }

begin case *cur_chr* **of**

open_node: \langle Implement `\openout` 1529 \rangle ;
write_node: \langle Implement `\write` 1530 \rangle ;
close_node: \langle Implement `\closeout` 1531 \rangle ;
special_node: \langle Implement `\special` 1532 \rangle ;
immediate_code: \langle Implement `\immediate` 1620 \rangle ;
set_language_code: \langle Implement `\setlanguage` 1622 \rangle ;
pdf_annot_node: \langle Implement `\pdfannot` 1556 \rangle ;
pdf_catalog_code: \langle Implement `\pdfcatalog` 1577 \rangle ;
pdf_dest_node: \langle Implement `\pdfdest` 1563 \rangle ;
pdf_end_link_node: \langle Implement `\pdfendlink` 1559 \rangle ;
pdf_end_thread_node: \langle Implement `\pdfendthread` 1567 \rangle ;
pdf_font_attr_code: \langle Implement `\pdffontattr` 1587 \rangle ;
pdf_font_expand_code: \langle Implement `\pdffontexpand` 1533 \rangle ;
pdf_include_chars_code: \langle Implement `\pdfincludechars` 1586 \rangle ;
pdf_info_code: \langle Implement `\pdfinfo` 1576 \rangle ;
pdf_literal_node: \langle Implement `\pdfliteral` 1536 \rangle ;
pdf_colorstack_node: \langle Implement `\pdfcolorstack` 1537 \rangle ;
pdf_setmatrix_node: \langle Implement `\pdfsetmatrix` 1538 \rangle ;
pdf_save_node: \langle Implement `\pdfsave` 1539 \rangle ;
pdf_restore_node: \langle Implement `\pdfrestore` 1540 \rangle ;
pdf_map_file_code: \langle Implement `\pdfmapfile` 1588 \rangle ;
pdf_map_line_code: \langle Implement `\pdfmapline` 1589 \rangle ;
pdf_names_code: \langle Implement `\pdfnames` 1578 \rangle ;
pdf_obj_code: \langle Implement `\pdfobj` 1542 \rangle ;
pdf_outline_code: \langle Implement `\pdfoutline` 1561 \rangle ;
pdf_refobj_node: \langle Implement `\pdfrefobj` 1544 \rangle ;
pdf_refxform_node: \langle Implement `\pdfrefxform` 1547 \rangle ;
pdf_refximage_node: \langle Implement `\pdfrefximage` 1552 \rangle ;
pdf_save_pos_node: \langle Implement `\pdfsavepos` 1574 \rangle ;
pdf_snap_ref_point_node: \langle Implement `\pdfsnaprefpoint` 1570 \rangle ;
pdf_snapyp_comp_node: \langle Implement `\pdfsnapypcomp` 1573 \rangle ;
pdf_snapyp_node: \langle Implement `\pdfsnapyp` 1572 \rangle ;
pdf_start_link_node: \langle Implement `\pdfstartlink` 1558 \rangle ;
pdf_start_thread_node: \langle Implement `\pdfstartthread` 1566 \rangle ;
pdf_thread_node: \langle Implement `\pdfthread` 1565 \rangle ;
pdf_trailer_code: \langle Implement `\pdftrailer` 1579 \rangle ;
pdf_trailer_id_code: \langle Implement `\pdftrailerid` 1580 \rangle ;
pdf_xform_code: \langle Implement `\pdfxform` 1546 \rangle ;
pdf_ximage_code: \langle Implement `\pdfximage` 1551 \rangle ;
reset_timer_code: \langle Implement `\pdfresettimer` 1584 \rangle ;
set_random_seed_code: \langle Implement `\pdfsetrandomseed` 1583 \rangle ;
pdf_glyph_to_unicode_code: \langle Implement `\pdfglyphtounicode` 1590 \rangle ;
pdf_nobuiltintounicode_code: \langle Implement `\pdfnobuiltintounicode` 1591 \rangle ;
pdf_interword_space_on_node: \langle Implement `\pdfinterwordspaceon` 1592 \rangle ;
pdf_interword_space_off_node: \langle Implement `\pdfinterwordspaceoff` 1593 \rangle ;
pdf_fake_space_node: \langle Implement `\pdffakespace` 1594 \rangle ;

```
pdf_running_link_off_node: ⟨Implement \pdfrunninglinkoff 1595⟩;
pdf_running_link_on_node: ⟨Implement \pdfrunninglinkon 1596⟩;
othercases confusion("ext1")
endcases;
end;
```

1527. Here is a subroutine that creates a *whatsit* node having a given *subtype* and a given number of words. It initializes only the first word of the *whatsit*, and appends it to the current list.

```
⟨Declare procedures needed in do_extension 1527⟩ ≡
procedure new_whatsit(s : small_number; w : small_number);
  var p : pointer; { the new node }
  begin p ← get_node(w); type(p) ← whatsit_node; subtype(p) ← s; link(tail) ← p; tail ← p;
  end;
```

See also sections 1528, 1535, 1550, 1554, 1560, 1564, 1571, 1575, 1585, and 1597.

This code is used in section 1526.

1528. The next subroutine uses *cur_chr* to decide what sort of *whatsit* is involved, and also inserts a *write_stream* number.

```
⟨Declare procedures needed in do_extension 1527⟩ +≡
procedure new_write_whatsit(w : small_number);
  begin new_whatsit(cur_chr, w);
  if w ≠ write_node_size then scan_four_bit_int
  else begin scan_int;
    if cur_val < 0 then cur_val ← 17
    else if cur_val > 15 then cur_val ← 16;
    end;
  write_stream(tail) ← cur_val;
  end;
```

```
1529. ⟨Implement \openout 1529⟩ ≡
  begin new_write_whatsit(open_node_size); scan_optional_equals; scan_file_name;
  open_name(tail) ← cur_name; open_area(tail) ← cur_area; open_ext(tail) ← cur_ext;
  end
```

This code is used in section 1526.

1530. When ‘\write 12{...}’ appears, we scan the token list ‘{...}’ without expanding its macros; the macros will be expanded later when this token list is rescanned.

```
⟨Implement \write 1530⟩ ≡
  begin k ← cur_cs; new_write_whatsit(write_node_size);
  cur_cs ← k; p ← scan_toks(false, false); write_tokens(tail) ← def_ref;
  end
```

This code is used in section 1526.

```
1531. ⟨Implement \closeout 1531⟩ ≡
  begin new_write_whatsit(write_node_size); write_tokens(tail) ← null;
  end
```

This code is used in section 1526.

1532. When ‘\special{...}’ appears, we expand the macros in the token list as in \xdef and \mark.

⟨Implement \special 1532⟩ ≡

```
begin new_whatsit(special_node, write_node_size); write_stream(tail) ← null; p ← scan_toks(false, true);
write_tokens(tail) ← def_ref;
end
```

This code is used in section 1526.

1533. ⟨Implement \pdffontexpand 1533⟩ ≡

```
read_expand_font
```

This code is used in section 1526.

1534. The following macros are needed for further manipulation with whatsit nodes for pdfTeX extensions (copying, destroying, etc.).

```
define add_action_ref(#) ≡ incr(pdf_action_refcount(#)) { increase count of references to this action }
define delete_action_ref(#) ≡
    { decrease count of references to this action; free it if there is no reference to this action }
begin if pdf_action_refcount(#) = null then
    begin if pdf_action_type(#) = pdf_action_user then delete_token_ref(pdf_action_user_tokens(#))
    else begin if pdf_action_file(#) ≠ null then delete_token_ref(pdf_action_file(#));
        if pdf_action_type(#) = pdf_action_page then delete_token_ref(pdf_action_page_tokens(#))
        else if pdf_action_named_id(#) > 0 then delete_token_ref(pdf_action_id(#));
        end;
    end
    free_node(#, pdf_action_size);
end
else decr(pdf_action_refcount(#));
end
```

1535. We have to check whether `\pdfoutput` is set for using pdfTeX extensions.

⟨Declare procedures needed in *do_extension* 1527⟩ +≡

```

procedure check_pdfoutput(s : str_number; is_error : boolean);
  begin if pdf_output ≤ 0 then
    begin if is_error then pdf_error(s, "not_allowed_in_DVI_mode_\pdfoutput_<=0")
    else pdf_warning(s, "not_allowed_in_DVI_mode_\pdfoutput_<=0;_ignoring_it", true, true);
    end
  end;
procedure scan_pdf_ext_toks;
  begin call_func(scan_toks(false, true)); { like \special }
  end;
procedure compare_strings; { to implement \pdfstrcmp }
  label done;
  var s1, s2 : str_number; i1, i2, j1, j2 : pool_pointer; save_cur_cs : pointer;
  begin save_cur_cs ← cur_cs; call_func(scan_toks(false, true)); s1 ← tokens_to_string(def_ref);
  delete_token_ref(def_ref); cur_cs ← save_cur_cs; call_func(scan_toks(false, true));
  s2 ← tokens_to_string(def_ref); delete_token_ref(def_ref); i1 ← str_start[s1]; j1 ← str_start[s1 + 1];
  i2 ← str_start[s2]; j2 ← str_start[s2 + 1];
  while (i1 < j1) ∧ (i2 < j2) do
    begin if str_pool[i1] < str_pool[i2] then
      begin cur_val ← -1; goto done;
      end;
    if str_pool[i1] > str_pool[i2] then
      begin cur_val ← 1; goto done;
      end;
    incr(i1); incr(i2);
    end;
    if (i1 = j1) ∧ (i2 = j2) then cur_val ← 0
    else if i1 < j1 then cur_val ← 1
    else cur_val ← -1;
  done: flush_str(s2); flush_str(s1); cur_val_level ← int_val;
  end;

```

1536. ⟨Implement `\pdfliteral` 1536⟩ ≡

```

begin check_pdfoutput("pdfliteral", true); new_whatsit(pdf_literal_node, write_node_size);
if scan_keyword("direct") then pdf_literal_mode(tail) ← direct_always
else if scan_keyword("page") then pdf_literal_mode(tail) ← direct_page
  else pdf_literal_mode(tail) ← set_origin;
  scan_pdf_ext_toks; pdf_literal_data(tail) ← def_ref;
end

```

This code is used in section 1526.

1537. $\langle \text{Implement } \backslash\text{pdfcolorstack } 1537 \rangle \equiv$

```

begin check_pdfoutput("\pdfcolorstack", true);
    { Scan and check the stack number and store in cur_val }
scan_int;
if cur_val  $\geq$  colorstackused then
    begin print_err("Unknown_color_stack_number"); print_int(cur_val);
    help3("Allocate_and_initialize_a_color_stack_with_\pdfcolorstackinit.")
    ("I'll_use_default_color_stack_0_here.")
    ("Proceed_with_fingers_crossed."); error; cur_val  $\leftarrow$  0;
    end;
if cur_val  $<$  0 then
    begin print_err("Invalid_negative_color_stack_number");
    help2("I'll_use_default_color_stack_0_here.")
    ("Proceed_with_fingers_crossed."); error; cur_val  $\leftarrow$  0;
    end; { Scan the command and store in i, j holds the node size }
if scan_keyword("set") then
    begin i  $\leftarrow$  colorstack_set; j  $\leftarrow$  pdf_colorstack_setter_node_size;
    end
else if scan_keyword("push") then
    begin i  $\leftarrow$  colorstack_push; j  $\leftarrow$  pdf_colorstack_setter_node_size;
    end
else if scan_keyword("pop") then
    begin i  $\leftarrow$  colorstack_pop; j  $\leftarrow$  pdf_colorstack_getter_node_size;
    end
else if scan_keyword("current") then
    begin i  $\leftarrow$  colorstack_current; j  $\leftarrow$  pdf_colorstack_getter_node_size;
    end
    else begin i  $\leftarrow$  -1; { error }
    end;
if i  $\geq$  0 then
    begin new_whatsit(pdf_colorstack_node, j); pdf_colorstack_stack(tail)  $\leftarrow$  cur_val;
    pdf_colorstack_cmd(tail)  $\leftarrow$  i;
    if i  $\leq$  colorstack_data then
        begin scan_pdf_ext_toks; pdf_colorstack_data(tail)  $\leftarrow$  def_ref;
        end;
    end
else begin print_err("Color_stack_action_is_missing");
    help3("The_expected_actions_for_\pdfcolorstack:")
    ("set, push, pop, current")
    ("I'll_ignore_the_color_stack_command."); error;
    end
end

```

This code is used in section 1526.

1538. $\langle \text{Implement } \backslash\text{pdfsetmatrix } 1538 \rangle \equiv$

```

begin check_pdfoutput("\pdfsetmatrix", true);
new_whatsit(pdf_setmatrix_node, pdf_setmatrix_node_size); scan_pdf_ext_toks;
pdf_setmatrix_data(tail)  $\leftarrow$  def_ref;
end

```

This code is used in section 1526.

1539. $\langle \text{Implement } \backslash\text{pdfsave } 1539 \rangle \equiv$

```
begin check_pdfoutput("\pdfsave", true); new_whatsit(pdf_save_node, pdf_save_node_size);
end
```

This code is used in section 1526.

1540. $\langle \text{Implement } \backslash\text{pdfrestore } 1540 \rangle \equiv$

```
begin check_pdfoutput("\pdfrestore", true); new_whatsit(pdf_restore_node, pdf_restore_node_size);
end
```

This code is used in section 1526.

1541. The `\pdfobj` primitive is used to create a “raw” object in the PDF output file. The object contents will be hold in memory and will be written out only when the object is referenced by `\pdfrefobj`. When `\pdfobj` is used with `\immediate`, the object contents will be written out immediately. Objects referenced in the current page are appended into *pdf_obj_list*.

$\langle \text{Global variables } 13 \rangle + \equiv$

pdf_last_obj: integer;

1542. $\langle \text{Implement } \backslash\text{pdfobj } 1542 \rangle \equiv$

```
begin check_pdfoutput("\pdfobj", true);
if scan_keyword("reserveobjnum") then
  begin  $\langle \text{Scan an optional space } 469 \rangle$ ;
  incr(pdf_obj_count); pdf_create_obj(obj_type_obj, pdf_obj_count); pdf_last_obj  $\leftarrow$  obj_ptr;
end
else begin  $k \leftarrow -1$ ;
  if scan_keyword("useobjnum") then
    begin scan_int;  $k \leftarrow \text{cur\_val}$ ;
    if  $(k \leq 0) \vee (k > \text{obj\_ptr}) \vee (\text{obj\_data\_ptr}(k) \neq 0)$  then
      begin pdf_warning("\pdfobj", "invalid_object_number_being_ignored", true, true);
      pdf_retval  $\leftarrow -1$ ; { signal the problem }
       $k \leftarrow -1$ ; { will be generated again }
      end;
    end;
  if  $k < 0$  then
    begin incr(pdf_obj_count); pdf_create_obj(obj_type_obj, pdf_obj_count);  $k \leftarrow \text{obj\_ptr}$ ;
    end;
  obj_data_ptr( $k$ )  $\leftarrow$  pdf_get_mem(pdfmem_obj_size);
  if scan_keyword("stream") then
    begin obj_obj_is_stream( $k$ )  $\leftarrow 1$ ;
    if scan_keyword("attr") then
      begin scan_pdf_ext_toks; obj_obj_stream_attr( $k$ )  $\leftarrow$  def_ref;
      end
    else obj_obj_stream_attr( $k$ )  $\leftarrow$  null;
    end
  else obj_obj_is_stream( $k$ )  $\leftarrow 0$ ;
  if scan_keyword("file") then obj_obj_is_file( $k$ )  $\leftarrow 1$ 
  else obj_obj_is_file( $k$ )  $\leftarrow 0$ ;
  scan_pdf_ext_toks; obj_obj_data( $k$ )  $\leftarrow$  def_ref; pdf_last_obj  $\leftarrow k$ ;
  end;
end
```

This code is used in section 1526.

1543. We need to check whether the referenced object exists.

⟨Declare procedures that need to be declared forward for pdfTeX 686⟩ +≡

```
function prev_rightmost(s, e : pointer): pointer;
    { finds the node preceding the rightmost node e; s is some node before e }
var p: pointer;
begin prev_rightmost ← null; p ← s;
if p = null then return;
while link(p) ≠ e do
    begin p ← link(p);
    if p = null then return;
    end;
prev_rightmost ← p;
end;
procedure pdf_check_obj(t, n : integer);
var k: integer;
begin k ← head_tab[t];
while (k ≠ 0) ∧ (k ≠ n) do k ← obj_link(k);
if k = 0 then pdf_error("ext1", "cannot_find_referenced_object");
end;
```

1544. ⟨Implement \pdfrefobj 1544⟩ ≡

```
begin check_pdfoutput("pdfrefobj", true); scan_int; pdf_check_obj(obj_type_obj, cur_val);
new_whatsit(pdf_refobj_node, pdf_refobj_node_size); pdf_obj_objnum(tail) ← cur_val;
end
```

This code is used in section 1526.

1545. \pdfxform and \pdfrefxform are similar to \pdfobj and \pdfrefobj.

⟨Global variables 13⟩ +≡

```
pdf_last_xform: integer;
```

1546. ⟨Implement \pdfxform 1546⟩ ≡

```
begin check_pdfoutput("pdfxform", true); incr(pdf_xform_count);
pdf_create_obj(obj_type_xform, pdf_xform_count); k ← obj_ptr;
obj_data_ptr(k) ← pdf_get_mem(pdfmem_xform_size);
if scan_keyword("attr") then
    begin scan_pdf_ext_toks; obj_xform_attr(k) ← def_ref;
    end
else obj_xform_attr(k) ← null;
if scan_keyword("resources") then
    begin scan_pdf_ext_toks; obj_xform_resources(k) ← def_ref;
    end
else obj_xform_resources(k) ← null;
scan_register_num; fetch_box(p);
if p = null then pdf_error("ext1", "\pdfxform_cannot_be_used_with_a_void_box");
obj_xform_width(k) ← width(p); obj_xform_height(k) ← height(p); obj_xform_depth(k) ← depth(p);
obj_xform_box(k) ← p; { save pointer to the box }
change_box(null); pdf_last_xform ← k;
end
```

This code is used in section 1526.

1547. $\langle \text{Implement } \backslash\text{pdfrefxform } 1547 \rangle \equiv$

```
begin check_pdfoutput("\pdfrefxform", true); scan_int; pdf_check_obj(obj_type_xform, cur_val);
new_whatsit(pdf_refxform_node, pdf_refxform_node_size); pdf_xform_objnum(tail)  $\leftarrow$  cur_val;
pdf_width(tail)  $\leftarrow$  obj_xform_width(cur_val); pdf_height(tail)  $\leftarrow$  obj_xform_height(cur_val);
pdf_depth(tail)  $\leftarrow$  obj_xform_depth(cur_val);
end
```

This code is used in section 1526.

1548. $\backslash\text{pdfximage}$ and $\backslash\text{pdfrefximage}$ are similar to $\backslash\text{pdfxform}$ and $\backslash\text{pdfrefxform}$. As we have to scan $\langle \text{rule spec} \rangle$ quite often, it is better have a rule_node that holds the most recently scanned $\langle \text{rule spec} \rangle$.

$\langle \text{Global variables } 13 \rangle + \equiv$

```
pdf_last_ximage: integer;
pdf_last_ximage_pages: integer;
pdf_last_ximage_colordepth: integer;
alt_rule: pointer;
warn_pdfpagebox: boolean;
```

1549. $\langle \text{Set initial values of key variables } 21 \rangle + \equiv$

```
alt_rule  $\leftarrow$  null; warn_pdfpagebox  $\leftarrow$  true;
```

1550. \langle Declare procedures needed in *do_extension* 1527 $\rangle + \equiv$

```

procedure scale_image(n : integer);
  var x, y, xr, yr: integer; { size and resolution of image }
  w, h: scaled; { indeed size corresponds to image resolution }
  default_res: integer; image: integer;
begin image  $\leftarrow$  obj_ximage_data(n);
if (image_rotate(image) = 90)  $\vee$  (image_rotate(image) = 270) then
  begin y  $\leftarrow$  image_width(image); x  $\leftarrow$  image_height(image); yr  $\leftarrow$  image_x_res(image);
    xr  $\leftarrow$  image_y_res(image);
  end
else begin x  $\leftarrow$  image_width(image); y  $\leftarrow$  image_height(image); xr  $\leftarrow$  image_x_res(image);
  yr  $\leftarrow$  image_y_res(image);
  end;
if (xr > 65535)  $\vee$  (yr > 65535) then
  begin xr  $\leftarrow$  0; yr  $\leftarrow$  0; pdf_warning("ext1", "too_large_image_resolution_ignored", true, true);
  end;
if (x  $\leq$  0)  $\vee$  (y  $\leq$  0)  $\vee$  (xr < 0)  $\vee$  (yr < 0) then pdf_error("ext1", "invalid_image_dimensions");
if is_pdf_image(image) then
  begin w  $\leftarrow$  x; h  $\leftarrow$  y;
  end
else begin default_res  $\leftarrow$  fix_int(pdf_image_resolution, 0, 65535);
  if (default_res > 0)  $\wedge$  ((xr = 0)  $\vee$  (yr = 0)) then
    begin xr  $\leftarrow$  default_res; yr  $\leftarrow$  default_res;
    end;
  if is_running(obj_ximage_width(n))  $\wedge$  is_running(obj_ximage_height(n)) then
    begin if (xr > 0)  $\wedge$  (yr > 0) then
      begin w  $\leftarrow$  ext_xn_over_d(one_hundred_inch, x, 100 * xr);
        h  $\leftarrow$  ext_xn_over_d(one_hundred_inch, y, 100 * yr);
      end
    else begin w  $\leftarrow$  ext_xn_over_d(one_hundred_inch, x, 7200);
      h  $\leftarrow$  ext_xn_over_d(one_hundred_inch, y, 7200);
    end;
    end;
  end;
if is_running(obj_ximage_width(n))  $\wedge$  is_running(obj_ximage_height(n))  $\wedge$  is_running(obj_ximage_depth(n))
  then
    begin obj_ximage_width(n)  $\leftarrow$  w; obj_ximage_height(n)  $\leftarrow$  h; obj_ximage_depth(n)  $\leftarrow$  0;
    end
  else if is_running(obj_ximage_width(n)) then
    begin { image depth or height is explicitly specified }
    if is_running(obj_ximage_height(n)) then
      begin { image depth is explicitly specified }
      obj_ximage_width(n)  $\leftarrow$  ext_xn_over_d(h, x, y); obj_ximage_height(n)  $\leftarrow$  h - obj_ximage_depth(n);
      end
    else if is_running(obj_ximage_depth(n)) then
      begin { image height is explicitly specified }
      obj_ximage_width(n)  $\leftarrow$  ext_xn_over_d(obj_ximage_height(n), x, y); obj_ximage_depth(n)  $\leftarrow$  0;
      end
    else begin { both image depth and height are explicitly specified }
      obj_ximage_width(n)  $\leftarrow$  ext_xn_over_d(obj_ximage_height(n) + obj_ximage_depth(n), x, y);
      end;
    end
  end

```

```

else begin { image width is explicitly specified }
  if is_running(obj_ximage_height(n)) ∧ is_running(obj_ximage_depth(n)) then
    begin { both image depth and height are not specified }
      obj_ximage_height(n) ← ext_xn_over_d(obj_ximage_width(n), y, x); obj_ximage_depth(n) ← 0;
    end { image depth is explicitly specified }
  else if is_running(obj_ximage_height(n)) then
    begin obj_ximage_height(n) ← ext_xn_over_d(obj_ximage_width(n), y, x) − obj_ximage_depth(n);
    end { image height is explicitly specified }
  else if is_running(obj_ximage_depth(n)) then
    begin obj_ximage_depth(n) ← 0;
    end { both image depth and height are explicitly specified }
  else do_nothing;
end;
end;

function scan_pdf_box_spec: integer; { scans PDF pagebox specification }
begin scan_pdf_box_spec ← 0;
if scan_keyword("mediabox") then scan_pdf_box_spec ← pdf_box_spec_media
else if scan_keyword("cropbox") then scan_pdf_box_spec ← pdf_box_spec_crop
  else if scan_keyword("bleedbox") then scan_pdf_box_spec ← pdf_box_spec_bleed
    else if scan_keyword("trimbox") then scan_pdf_box_spec ← pdf_box_spec_trim
      else if scan_keyword("artbox") then scan_pdf_box_spec ← pdf_box_spec_art
    end;
procedure scan_alt_rule; { scans rule spec to alt_rule }
label reswitch;
begin if alt_rule = null then alt_rule ← new_rule;
width(alt_rule) ← null_flag; height(alt_rule) ← null_flag; depth(alt_rule) ← null_flag;
reswitch: if scan_keyword("width") then
  begin scan_normal_dimen; width(alt_rule) ← cur_val; goto reswitch;
end;
if scan_keyword("height") then
  begin scan_normal_dimen; height(alt_rule) ← cur_val; goto reswitch;
end;
if scan_keyword("depth") then
  begin scan_normal_dimen; depth(alt_rule) ← cur_val; goto reswitch;
end;
end;
procedure scan_image;
label reswitch;
var k: integer; named: str_number; s: str_number; page, pagebox, colorspace: integer;
begin incr(pdf_ximage_count); pdf_create_obj(obj_type_ximage, pdf_ximage_count); k ← obj_ptr;
obj_data_ptr(k) ← pdf_get_mem(pdfmem_ximage_size); scan_alt_rule; { scans < rulespec > to alt_rule }
obj_ximage_width(k) ← width(alt_rule); obj_ximage_height(k) ← height(alt_rule);
obj_ximage_depth(k) ← depth(alt_rule);
if scan_keyword("attr") then
  begin scan_pdf_ext_toks; obj_ximage_attr(k) ← def_ref;
end
else obj_ximage_attr(k) ← null;
named ← 0;
if scan_keyword("named") then
  begin scan_pdf_ext_toks; named ← tokens_to_string(def_ref); delete_token_ref(def_ref);
end
else if scan_keyword("page") then

```



```

    begin scan_int; page ← cur_val;
    end
    else page ← 1;
if scan_keyword("colorspace") then
    begin scan_int; colorspace ← cur_val;
    end
else colorspace ← 0;
pagebox ← scan_pdf_box_spec;
if pagebox = 0 then pagebox ← pdf_pagebox;
scan_pdf_ext_toks; s ← tokens_to_string(def_ref); delete_token_ref(def_ref);
if pdf_option_always_use_pdfpagebox ≠ 0 then
    begin pdf_warning("PDF_inclusion",
        "Primitive_\pdfoptionalwaysusepdfpagebox_is_obsolete;_use_\pdfpagebox_instead.",
        true, true); pdf_force_pagebox ← pdf_option_always_use_pdfpagebox;
    pdf_option_always_use_pdfpagebox ← 0; { warn once }
    warn_pdfpagebox ← false;
    end;
if pdf_option_pdf_inclusion_errorlevel ≠ 0 then
    begin pdf_warning("PDF_inclusion",
        "Primitive_\pdfoptionpdfinclusionerrorlevel_is_obsolete;_use_\pdfinclusionerrorlevel_instead.",
        true, true); pdf_inclusion_errorlevel ← pdf_option_pdf_inclusion_errorlevel;
    pdf_option_pdf_inclusion_errorlevel ← 0; { warn once }
    end;
if pdf_force_pagebox > 0 then
    begin if warn_pdfpagebox then
        begin pdf_warning("PDF_inclusion",
            "Primitive_\pdfforcepagebox_is_obsolete;_use_\pdfpagebox_instead.", true, true);
        warn_pdfpagebox ← false;
        end;
    end;
    pagebox ← pdf_force_pagebox;
end;
if pagebox = 0 then { no pagebox specification given }
    pagebox ← pdf_box_spec_crop;
obj_ximage_data(k) ← read_image(s, page, named, colorspace, pagebox, pdf_major_version,
    pdf_minor_version, pdf_inclusion_errorlevel);
if named ≠ 0 then flush_str(named);
flush_str(s); scale_image(k); pdf_last_ximage ← k;
pdf_last_ximage_pages ← image_pages(obj_ximage_data(k));
pdf_last_ximage_colordepth ← image_colordepth(obj_ximage_data(k));
end;

```

1551. $\langle \text{Implement } \backslash\text{pdfximage } 1551 \rangle \equiv$

```

    begin check_pdfoutput("\pdfximage", true); check_pdfversion; scan_image;
    end

```

This code is used in section 1526.

1552. $\langle \text{Implement } \backslash\text{pdfrefximage } 1552 \rangle \equiv$

```
begin check_pdfoutput("\pdfrefximage", true); scan_int; pdf_check_obj(obj_type_ximage, cur_val);
new_whatsit(pdf_refximage_node, pdf_refximage_node_size); pdf_ximage_objnum(tail) ← cur_val;
pdf_width(tail) ← obj_ximage_width(cur_val); pdf_height(tail) ← obj_ximage_height(cur_val);
pdf_depth(tail) ← obj_ximage_depth(cur_val);
end
```

This code is used in section 1526.

1553. The following function finds object with identifier i and type t . $i < 0$ indicates that $-i$ should be treated as a string number. If no such object exists then it will be created. This function is used mainly to find destination for link annotations and outlines; however it is also used in *pdf_ship_out* (to check whether a Page object already exists) so we need to declare it together with subroutines needed in *pdf_hlist_out* and *pdf_vlist_out*.

$\langle \text{Declare procedures that need to be declared forward for pdfTeX } 686 \rangle + \equiv$

```
function find_obj(t, i : integer; byname : boolean): integer;
begin find_obj ← avl_find_obj(t, i, byname);
end;
procedure flush_str(s : str_number); { flush a string if possible }
begin if flushable(s) then flush_string;
end;
function get_obj(t, i : integer; byname : boolean): integer;
var r: integer; s: str_number;
begin if byname > 0 then
begin s ← tokens_to_string(i); r ← find_obj(t, s, true);
end
else begin s ← 0; r ← find_obj(t, i, false);
end;
if r = 0 then
begin if byname > 0 then
begin pdf_create_obj(t, -s); s ← 0;
end
else pdf_create_obj(t, i);
r ← obj_ptr;
if t = obj_type_dest then obj_dest_ptr(r) ← null;
end;
if s ≠ 0 then flush_str(s);
get_obj ← r;
end;
function get_microinterval: integer;
var s, m: integer; { seconds and microseconds }
begin seconds_and_micros(s, m);
if (s - epochseconds) > 32767 then get_microinterval ← max_integer
else if (microseconds > m) then
get_microinterval ← ((s - 1 - epochseconds) * 65536) + (((m + 1000000 - microseconds) / 100) * 65536) / 10000
else get_microinterval ← ((s - epochseconds) * 65536) + (((m - microseconds) / 100) * 65536) / 10000;
end;
```

1554. \langle Declare procedures needed in *do_extension 1527* $\rangle + \equiv$

```

function scan_action: pointer; { read an action specification }
  var p: integer;
  begin p  $\leftarrow$  get_node(pdf_action_size); scan_action  $\leftarrow$  p; pdf_action_file(p)  $\leftarrow$  null;
  pdf_action_refcount(p)  $\leftarrow$  null;
  if scan_keyword("user") then pdf_action_type(p)  $\leftarrow$  pdf_action_user
  else if scan_keyword("goto") then pdf_action_type(p)  $\leftarrow$  pdf_action_goto
    else if scan_keyword("thread") then pdf_action_type(p)  $\leftarrow$  pdf_action_thread
      else pdf_error("ext1", "action_type_missing");
  if pdf_action_type(p) = pdf_action_user then
    begin scan_pdf_ext_toks; pdf_action_user_tokens(p)  $\leftarrow$  def_ref; return;
    end;
  if scan_keyword("file") then
    begin scan_pdf_ext_toks; pdf_action_file(p)  $\leftarrow$  def_ref;
    end;
  if scan_keyword("page") then
    begin if pdf_action_type(p)  $\neq$  pdf_action_goto then
      pdf_error("ext1", "only_GoTo_action_can_be_used_with_page");
      pdf_action_type(p)  $\leftarrow$  pdf_action_page; scan_int;
      if cur_val  $\leq$  0 then pdf_error("ext1", "page_number_must_be_positive");
      pdf_action_id(p)  $\leftarrow$  cur_val; pdf_action_named_id(p)  $\leftarrow$  0; scan_pdf_ext_toks;
      pdf_action_page_tokens(p)  $\leftarrow$  def_ref;
    end
  else if scan_keyword("name") then
    begin scan_pdf_ext_toks; pdf_action_named_id(p)  $\leftarrow$  1; pdf_action_id(p)  $\leftarrow$  def_ref;
    end
  else if scan_keyword("num") then
    begin if (pdf_action_type(p) = pdf_action_goto)  $\wedge$  (pdf_action_file(p)  $\neq$  null) then
      pdf_error("ext1", "`goto` option cannot be used with both `file` and `num`");
      scan_int;
      if cur_val  $\leq$  0 then pdf_error("ext1", "num_identifier_must_be_positive");
      pdf_action_named_id(p)  $\leftarrow$  0; pdf_action_id(p)  $\leftarrow$  cur_val;
    end
    else pdf_error("ext1", "identifier_type_missing");
  if scan_keyword("newwindow") then
    begin pdf_action_new_window(p)  $\leftarrow$  1;  $\langle$  Scan an optional space 469  $\rangle$ ;
    end
  else if scan_keyword("nonewwindow") then
    begin pdf_action_new_window(p)  $\leftarrow$  2;  $\langle$  Scan an optional space 469  $\rangle$ ;
    end
    else pdf_action_new_window(p)  $\leftarrow$  0;
  if (pdf_action_new_window(p)  $>$  0)  $\wedge$  (((pdf_action_type(p)  $\neq$  pdf_action_goto)  $\wedge$  (pdf_action_type(p)  $\neq$  pdf_action_page))  $\vee$  (pdf_action_file(p) = null)) then
    pdf_error("ext1", "`newwindow`/`nonewwindow` must be used with `goto` and `file` option");
  end;
procedure new_annot_whatsit(w, s: small_number); { create a new whatsit node for annotation }
  begin new_whatsit(w, s); scan_alt_rule; { scans  $\langle$  rule_spec  $\rangle$  to alt_rule }
  pdf_width(tail)  $\leftarrow$  width(alt_rule); pdf_height(tail)  $\leftarrow$  height(alt_rule); pdf_depth(tail)  $\leftarrow$  depth(alt_rule);
  if (w = pdf_start_link_node) then
    begin if scan_keyword("attr") then
      begin scan_pdf_ext_toks; pdf_link_attr(tail)  $\leftarrow$  def_ref;
      end
    end

```

```

    else pdf_link_attr(tail) ← null;
  end;
if (w = pdf_thread_node) ∨ (w = pdf_start_thread_node) then
  begin if scan_keyword("attr") then
    begin scan_pdf_ext_toks; pdf_thread_attr(tail) ← def_ref;
    end
    else pdf_thread_attr(tail) ← null;
    end;
end;
end;

```

1555. ⟨Global variables 13⟩ +≡
pdf_last_annot: integer;

1556. ⟨Implement \pdfannot 1556⟩ ≡
 begin check_pdfoutput("\pdfannot", true);
 if scan_keyword("reserveobjnum") then
 begin pdf_last_annot ← pdf_new_objnum; ⟨Scan an optional space 469⟩;
 end
 else begin if scan_keyword("useobjnum") then
 begin scan_int; k ← cur_val;
 if (k ≤ 0) ∨ (k > obj_ptr) ∨ (obj_annot_ptr(k) ≠ 0) then
 pdf_error("ext1", "invalid_object_number");
 end
 else k ← pdf_new_objnum;
 new_annot_whatsit(pdf_annot_node, pdf_annot_node_size); pdf_annot_objnum(tail) ← k;
 scan_pdf_ext_toks; pdf_annot_data(tail) ← def_ref; pdf_last_annot ← k;
 end
 end
end

This code is used in section 1526.

1557. \pdflastlink needs an extra global variable.

⟨Global variables 13⟩ +≡
pdf_last_link: integer;

1558. ⟨Implement \pdfstartlink 1558⟩ ≡
 begin check_pdfoutput("\pdfstartlink", true);
 if abs(mode) = vmode then
 pdf_error("ext1", "\pdfstartlink_cannot_be_used_in_vertical_mode");
 k ← pdf_new_objnum; new_annot_whatsit(pdf_start_link_node, pdf_annot_node_size);
 pdf_link_action(tail) ← scan_action; pdf_link_objnum(tail) ← k; pdf_last_link ← k; { N.B.: although it is
 possible to set obj_annot_ptr(k) ← tail here, it is not safe if nodes are later copied/destroyed/moved;
 a better place to do this is inside do_link, when the whatsit node is written out }
 end
end

This code is used in section 1526.

1559. ⟨Implement \pdfendlink 1559⟩ ≡
 begin check_pdfoutput("\pdfendlink", true);
 if abs(mode) = vmode then pdf_error("ext1", "\pdfendlink_cannot_be_used_in_vertical_mode");
 new_whatsit(pdf_end_link_node, small_node_size);
 end

This code is used in section 1526.

1560. \langle Declare procedures needed in *do_extension* 1527 $\rangle + \equiv$

```
function outline_list_count(p : pointer): integer;
  { return number of outline entries in the same level with p }
var k: integer;
begin k  $\leftarrow$  1;
while obj_outline_prev(p)  $\neq$  0 do
  begin incr(k); p  $\leftarrow$  obj_outline_prev(p);
  end;
outline_list_count  $\leftarrow$  k;
end;
```

1561. \langle Implement `\pdfoutline` 1561 $\rangle \equiv$

```
begin check_pdfoutput("pdfoutline", true);
if scan_keyword("attr") then
  begin scan_pdf_ext_toks; r  $\leftarrow$  def_ref;
  end
else r  $\leftarrow$  0;
p  $\leftarrow$  scan_action;
if scan_keyword("count") then
  begin scan_int; i  $\leftarrow$  cur_val;
  end
else i  $\leftarrow$  0;
scan_pdf_ext_toks; q  $\leftarrow$  def_ref; pdf_new_obj(obj_type_others, 0, 1); j  $\leftarrow$  obj_ptr; write_action(p);
pdf_end_obj; delete_action_ref(p); pdf_create_obj(obj_type_outline, 0); k  $\leftarrow$  obj_ptr;
obj_outline_ptr(k)  $\leftarrow$  pdf_get_mem(pdfmem_outline_size); obj_outline_action_objnum(k)  $\leftarrow$  j;
obj_outline_count(k)  $\leftarrow$  i; pdf_new_obj(obj_type_others, 0, 1); pdf_print_str_ln(tokens_to_string(q));
flush_str(last_tokens_string); delete_token_ref(q); pdf_end_obj; obj_outline_title(k)  $\leftarrow$  obj_ptr;
obj_outline_prev(k)  $\leftarrow$  0; obj_outline_next(k)  $\leftarrow$  0; obj_outline_first(k)  $\leftarrow$  0; obj_outline_last(k)  $\leftarrow$  0;
obj_outline_parent(k)  $\leftarrow$  pdf_parent_outline; obj_outline_attr(k)  $\leftarrow$  r;
if pdf_first_outline = 0 then pdf_first_outline  $\leftarrow$  k;
if pdf_last_outline = 0 then
  begin if pdf_parent_outline  $\neq$  0 then obj_outline_first(pdf_parent_outline)  $\leftarrow$  k;
  end
else begin obj_outline_next(pdf_last_outline)  $\leftarrow$  k; obj_outline_prev(k)  $\leftarrow$  pdf_last_outline;
  end;
pdf_last_outline  $\leftarrow$  k;
if obj_outline_count(k)  $\neq$  0 then
  begin pdf_parent_outline  $\leftarrow$  k; pdf_last_outline  $\leftarrow$  0;
  end
else if (pdf_parent_outline  $\neq$  0)  $\wedge$  (outline_list_count(k) = abs(obj_outline_count(pdf_parent_outline)))
  then
    begin j  $\leftarrow$  pdf_last_outline;
    repeat obj_outline_last(pdf_parent_outline)  $\leftarrow$  j; j  $\leftarrow$  pdf_parent_outline;
      pdf_parent_outline  $\leftarrow$  obj_outline_parent(pdf_parent_outline);
    until (pdf_parent_outline = 0)  $\vee$  (outline_list_count(j) < abs(obj_outline_count(pdf_parent_outline)));
    if pdf_parent_outline = 0 then pdf_last_outline  $\leftarrow$  pdf_first_outline
    else pdf_last_outline  $\leftarrow$  obj_outline_first(pdf_parent_outline);
    while obj_outline_next(pdf_last_outline)  $\neq$  0 do pdf_last_outline  $\leftarrow$  obj_outline_next(pdf_last_outline);
    end;
  end
end
```

This code is used in section 1526.

1562. When a destination is created we need to check whether another destination with the same identifier already exists and give a warning if needed.

⟨ Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727 ⟩ +≡

```
procedure warn_dest_dup(id : integer; byname : small_number; s1, s2 : str_number);
  begin if pdf_suppress_warning_dup_dest > 0 then return;
  pdf_warning(s1, "destination_with_the_same_identifier(", false, false);
  if byname > 0 then
    begin print("name"); print_mark(id);
    end
  else begin print("num"); print_int(id);
    end;
  print(")_"); print(s2); print_ln; show_context;
end;
```

1563. Notice that *scan_keyword* doesn't care if two words have same prefix; so we should be careful when scan keywords with same prefix. The main rule: if there are two or more keywords with the same prefix, then always test in order from the longest one to the shortest one.

```

⟨Implement \pdfdest 1563⟩ ≡
  begin check_pdfoutput("\pdfdest", true); q ← tail; new_whatsit(pdf_dest_node, pdf_dest_node_size);
  if scan_keyword("num") then
    begin scan_int;
    if cur_val ≤ 0 then pdf_error("ext1", "num_identifier_must_be_positive");
    if cur_val > max_halfword then pdf_error("ext1", "number_too_big");
    pdf_dest_id(tail) ← cur_val; pdf_dest_named_id(tail) ← 0;
    end
  else if scan_keyword("name") then
    begin scan_pdf_ext_toks; pdf_dest_id(tail) ← def_ref; pdf_dest_named_id(tail) ← 1;
    end
    else pdf_error("ext1", "identifier_type_missing");
  if scan_keyword("xyz") then
    begin pdf_dest_type(tail) ← pdf_dest_xyz;
    if scan_keyword("zoom") then
      begin scan_int;
      if cur_val > max_halfword then pdf_error("ext1", "number_too_big");
      pdf_dest_xyz_zoom(tail) ← cur_val;
      end
    else pdf_dest_xyz_zoom(tail) ← null;
    end
  else if scan_keyword("fitbh") then pdf_dest_type(tail) ← pdf_dest_fitbh
  else if scan_keyword("fitbv") then pdf_dest_type(tail) ← pdf_dest_fitbv
  else if scan_keyword("fitb") then pdf_dest_type(tail) ← pdf_dest_fitb
  else if scan_keyword("fith") then pdf_dest_type(tail) ← pdf_dest_fith
  else if scan_keyword("fitv") then pdf_dest_type(tail) ← pdf_dest_fitv
  else if scan_keyword("fitr") then pdf_dest_type(tail) ← pdf_dest_fitr
  else if scan_keyword("fit") then pdf_dest_type(tail) ← pdf_dest_fit
  else pdf_error("ext1", "destination_type_missing");
  ⟨Scan an optional space 469⟩;
  if pdf_dest_type(tail) = pdf_dest_fitr then
    begin scan_alt_rule; { scans < rule_spec > to alt_rule }
    pdf_width(tail) ← width(alt_rule); pdf_height(tail) ← height(alt_rule);
    pdf_depth(tail) ← depth(alt_rule);
    end;
  if pdf_dest_named_id(tail) ≠ 0 then
    begin i ← tokens_to_string(pdf_dest_id(tail)); k ← find_obj(obj_type_dest, i, true); flush_str(i);
    end
  else k ← find_obj(obj_type_dest, pdf_dest_id(tail), false);
  if (k ≠ 0) ∧ (obj_dest_ptr(k) ≠ null) then
    begin warn_dest_dup(pdf_dest_id(tail), pdf_dest_named_id(tail), "ext4",
      "has_been_already_used,_duplicate_ignored"); flush_node_list(tail); tail ← q;
    link(q) ← null;
    end;
  end
end

```

This code is used in section 1526.

1564. \langle Declare procedures needed in *do_extension* 1527 $\rangle + \equiv$

```

procedure scan_thread_id;
begin if scan_keyword("num") then
  begin scan_int;
  if cur_val  $\leq$  0 then pdf_error("ext1", "num_identifier_must_be_positive");
  if cur_val > max_halfword then pdf_error("ext1", "number_too_big");
  pdf_thread_id(tail)  $\leftarrow$  cur_val; pdf_thread_named_id(tail)  $\leftarrow$  0;
  end
else if scan_keyword("name") then
  begin scan_pdf_ext_toks; pdf_thread_id(tail)  $\leftarrow$  def_ref; pdf_thread_named_id(tail)  $\leftarrow$  1;
  end
  else pdf_error("ext1", "identifier_type_missing");
end;

```

1565. \langle Implement `\pdfthread` 1565 $\rangle \equiv$

```

begin check_pdfoutput("pdfthread", true); new_annot_whatsit(pdf_thread_node, pdf_thread_node_size);
scan_thread_id;
end

```

This code is used in section 1526.

1566. \langle Implement `\pdfstartthread` 1566 $\rangle \equiv$

```

begin check_pdfoutput("pdfstartthread", true);
new_annot_whatsit(pdf_start_thread_node, pdf_thread_node_size); scan_thread_id;
end

```

This code is used in section 1526.

1567. \langle Implement `\pdfendthread` 1567 $\rangle \equiv$

```

begin check_pdfoutput("pdfendthread", true); new_whatsit(pdf_end_thread_node, small_node_size);
end

```

This code is used in section 1526.

1568. \langle Global variables 13 $\rangle + \equiv$

```

pdf_last_x_pos: integer;
pdf_last_y_pos: integer;
pdf_snapx_refpos: integer;
pdf_snapy_refpos: integer;
count_do_snapx: integer;

```

1569. \langle Set initial values of key variables 21 $\rangle + \equiv$

```

count_do_snapx  $\leftarrow$  0;

```

1570. \langle Implement `\pdfsnaprefpoint` 1570 $\rangle \equiv$

```

begin check_pdfoutput("pdfsnaprefpoint", true);
new_whatsit(pdf_snap_ref_point_node, small_node_size);
end

```

This code is used in section 1526.

1571. \langle Declare procedures needed in *do_extension 1527* $\rangle + \equiv$

```
function new_snap_node(s : small_number): pointer;
  var p: pointer;
  begin scan_glue(glue_val);
  if width(cur_val) < 0 then pdf_error("ext1", "negative_snap_glue");
  p  $\leftarrow$  get_node(snap_node_size); type(p)  $\leftarrow$  whatsit_node; subtype(p)  $\leftarrow$  s; link(p)  $\leftarrow$  null;
  snap_glue_ptr(p)  $\leftarrow$  cur_val; final_skip(p)  $\leftarrow$  0; new_snap_node  $\leftarrow$  p;
  end;
```

1572. \langle Implement `\pdfsnappy 1572` $\rangle \equiv$

```
begin check_pdfoutput("pdfsnappy", true); tail_append(new_snap_node(pdf_snappy_node));
end
```

This code is used in section 1526.

1573. \langle Implement `\pdfsnappycomp 1573` $\rangle \equiv$

```
begin check_pdfoutput("pdfsnappycomp", true); new_whatsit(pdf_snappy_comp_node, small_node_size);
scan_int; snappy_comp_ratio(tail)  $\leftarrow$  fix_int(cur_val, 0, 1000);
end
```

This code is used in section 1526.

1574. \langle Implement `\pdfsavepos 1574` $\rangle \equiv$

```
begin new_whatsit(pdf_save_pos_node, small_node_size);
end
```

This code is used in section 1526.

1575. To implement primitives as `\pdfinfo`, `\pdfcatalog` or `\pdfnames` we need to concatenate tokens lists.

\langle Declare procedures needed in *do_extension 1527* $\rangle + \equiv$

```
function concat_tokens(q, r : pointer): pointer; { concat q and r and returns the result tokens list }
  var p: pointer;
  begin if q = null then
    begin concat_tokens  $\leftarrow$  r; return;
    end;
  p  $\leftarrow$  q;
  while link(p)  $\neq$  null do p  $\leftarrow$  link(p);
  link(p)  $\leftarrow$  link(r); free_avail(r); concat_tokens  $\leftarrow$  q;
  end;
```

1576. \langle Implement `\pdfinfo 1576` $\rangle \equiv$

```
begin check_pdfoutput("pdfinfo", false); scan_pdf_ext_toks;
if pdf_output > 0 then pdf_info_toks  $\leftarrow$  concat_tokens(pdf_info_toks, def_ref);
end
```

This code is used in section 1526.

```

1577. ⟨Implement \pdfcatalog 1577⟩ ≡
begin check_pdfoutput("\pdfcatalog",false); scan_pdf_ext_toks;
if pdf_output > 0 then pdf_catalog_toks ← concat_tokens(pdf_catalog_toks,def_ref);
if scan_keyword("openaction") then
begin if pdf_catalog_openaction ≠ 0 then pdf_error("ext1","duplicate_of_openaction")
else begin p ← scan_action; pdf_new_obj(obj_type_others,0,1);
if pdf_output > 0 then pdf_catalog_openaction ← obj_ptr;
write_action(p); pdf_end_obj; delete_action_ref(p);
end;
end
end

```

This code is used in section 1526.

```

1578. ⟨Implement \pdfnames 1578⟩ ≡
begin check_pdfoutput("\pdfnames",true); scan_pdf_ext_toks;
pdf_names_toks ← concat_tokens(pdf_names_toks,def_ref);
end

```

This code is used in section 1526.

```

1579. ⟨Implement \pdftrailer 1579⟩ ≡
begin check_pdfoutput("\pdftrailer",false); scan_pdf_ext_toks;
if pdf_output > 0 then pdf_trailer_toks ← concat_tokens(pdf_trailer_toks,def_ref);
end

```

This code is used in section 1526.

```

1580. ⟨Implement \pdftrailerid 1580⟩ ≡
begin check_pdfoutput("\pdftrailerid",false); scan_pdf_ext_toks;
if pdf_output > 0 then pdf_trailer_id_toks ← concat_tokens(pdf_trailer_id_toks,def_ref);
end

```

This code is used in section 1526.

```

1581. ⟨Global variables 13⟩ +≡
pdf_retval: integer; { global multi-purpose return value }

```

```

1582. ⟨Set initial values of key variables 21⟩ +≡
seconds_and_micros(epochseconds,microseconds); init_start_time;

```

1583. Negative random seed values are silently converted to positive ones.

```

⟨Implement \pdfsetrandomseed 1583⟩ ≡
begin scan_int;
if cur_val < 0 then negate(cur_val);
random_seed ← cur_val; init_randoms(random_seed);
end

```

This code is used in section 1526.

```

1584. ⟨Implement \pdfresettimer 1584⟩ ≡
begin seconds_and_micros(epochseconds,microseconds);
end

```

This code is used in section 1526.

1585. The following subroutines are about PDF-specific font issues.

⟨Declare procedures needed in *do_extension* 1527⟩ +≡

```
procedure pdf_include_chars;
  var s: str_number; k: pool_pointer; { running indices }
      f: internal_font_number;
begin scan_font_ident; f ← cur_val;
if f = null_font then pdf_error("font", "invalid_font_identifier");
pdf_check_vf_cur_val;
if ¬font_used[f] then pdf_init_font(f);
scan_pdf_ext_toks; s ← tokens_to_string(def_ref); delete_token_ref(def_ref); k ← str_start[s];
while k < str_start[s + 1] do
  begin pdf_mark_char(f, str_pool[k]); incr(k);
  end;
flush_str(s);
end;
procedure glyph_to_unicode;
  var s1, s2: str_number;
begin scan_pdf_ext_toks; s1 ← tokens_to_string(def_ref); delete_token_ref(def_ref); scan_pdf_ext_toks;
s2 ← tokens_to_string(def_ref); delete_token_ref(def_ref); def_tounicode(s1, s2); flush_str(s2);
flush_str(s1);
end;
```

1586. ⟨Implement \pdfincludechars 1586⟩ ≡

```
begin check_pdfoutput("\pdfincludechars", true); pdf_include_chars;
end
```

This code is used in section 1526.

1587. ⟨Implement \pdffontattr 1587⟩ ≡

```
begin check_pdfoutput("\pdffontattr", true); scan_font_ident; k ← cur_val;
if k = null_font then pdf_error("font", "invalid_font_identifier");
scan_pdf_ext_toks; pdf_font_attr[k] ← tokens_to_string(def_ref);
end
```

This code is used in section 1526.

1588. ⟨Implement \pdfmapfile 1588⟩ ≡

```
begin check_pdfoutput("\pdfmapfile", true); scan_pdf_ext_toks; pdfmapfile(def_ref);
delete_token_ref(def_ref);
end
```

This code is used in section 1526.

1589. ⟨Implement \pdfmapline 1589⟩ ≡

```
begin check_pdfoutput("\pdfmapline", true); scan_pdf_ext_toks; pdfmapline(def_ref);
delete_token_ref(def_ref);
end
```

This code is used in section 1526.

1590. ⟨Implement \pdfglyptounicode 1590⟩ ≡

```
begin glyph_to_unicode;
end
```

This code is used in section 1526.

```

1591.  $\langle$  Implement \pdfnombuiltintounicode 1591  $\rangle \equiv$ 
  begin check_pdfoutput("pdfnombuiltintounicode", true); scan_font_ident; k  $\leftarrow$  cur_val;
  if k = null_font then pdf_error("font", "invalid_font_identifier");
  pdf_font_nombuiltin_tounicode[k]  $\leftarrow$  true;
  end

```

This code is used in section 1526.

```

1592.  $\langle$  Implement \pdfinterwordspaceon 1592  $\rangle \equiv$ 
  begin check_pdfoutput("pdfinterwordspaceon", true);
  new_whatsit(pdf_interword_space_on_node, small_node_size);
  end

```

This code is used in section 1526.

```

1593.  $\langle$  Implement \pdfinterwordspaceoff 1593  $\rangle \equiv$ 
  begin check_pdfoutput("pdfinterwordspaceoff", true);
  new_whatsit(pdf_interword_space_off_node, small_node_size);
  end

```

This code is used in section 1526.

```

1594.  $\langle$  Implement \pdffakespace 1594  $\rangle \equiv$ 
  begin check_pdfoutput("pdffakespace", true); new_whatsit(pdf_fake_space_node, small_node_size);
  end

```

This code is used in section 1526.

```

1595.  $\langle$  Implement \pdfrunninglinkoff 1595  $\rangle \equiv$ 
  begin check_pdfoutput("pdfrunninglinkoff", true);
  new_whatsit(pdf_running_link_off_node, small_node_size);
  end

```

This code is used in section 1526.

```

1596.  $\langle$  Implement \pdfrunninglinkon 1596  $\rangle \equiv$ 
  begin check_pdfoutput("pdfrunninglinkon", true);
  new_whatsit(pdf_running_link_on_node, small_node_size);
  end

```

This code is used in section 1526.

1597. The following function are needed for outputting article thread.

⟨Declare procedures needed in *do_extension* 1527⟩ +≡

```

procedure thread_title(thread : integer);
  begin pdf_print("/Title_");
  if obj_info(thread) < 0 then pdf_print(-obj_info(thread))
  else pdf_print_int(obj_info(thread));
  pdf_print_ln("");
  end;

procedure pdf_fix_thread(thread : integer);
  var a: pointer;
  begin pdf_warning("thread", "destination_", false, false);
  if obj_info(thread) < 0 then
    begin print("name{"); print(-obj_info(thread)); print("}");
    end
  else begin print("num"); print_int(obj_info(thread));
    end;
  print("_has_been_referenced_but_does_not_exist,_replaced_by_a_fixed_one"); print_ln;
  print_ln; pdf_new_dict(obj_type_others, 0, 0); a ← obj_ptr; pdf_indirect_ln("T", thread);
  pdf_indirect_ln("V", a); pdf_indirect_ln("N", a); pdf_indirect_ln("P", head_tab[obj_type_page]);
  pdf_print("/R_[0_0_]"); pdf_print_bp(pdf_page_width); pdf_out("_"); pdf_print_bp(pdf_page_height);
  pdf_print_ln("]"); pdf_end_dict; pdf_begin_dict(thread, 1); pdf_print_ln("/I_<<_"); thread_title(thread);
  pdf_print_ln(">>"); pdf_indirect_ln("F", a); pdf_end_dict;
  end;

procedure out_thread(thread : integer);
  var a, b: pointer; last_attr: integer;
  begin if obj_thread_first(thread) = 0 then
    begin pdf_fix_thread(thread); return;
    end;
  pdf_begin_dict(thread, 1); a ← obj_thread_first(thread); b ← a; last_attr ← 0;
  repeat if obj_bead_attr(a) ≠ 0 then last_attr ← obj_bead_attr(a);
    a ← obj_bead_next(a);
  until a = b;
  if last_attr ≠ 0 then pdf_print_ln(last_attr)
  else begin pdf_print_ln("/I_<<_"); thread_title(thread); pdf_print_ln(">>");
    end;
  pdf_indirect_ln("F", a); pdf_end_dict;
  repeat pdf_begin_dict(a, 1);
    if a = b then pdf_indirect_ln("T", thread);
    pdf_indirect_ln("V", obj_bead_prev(a)); pdf_indirect_ln("N", obj_bead_next(a));
    pdf_indirect_ln("P", obj_bead_page(a)); pdf_indirect_ln("R", obj_bead_rect(a)); pdf_end_dict;
    a ← obj_bead_next(a);
  until a = b;
  end;

```

1598. ⟨Display rule spec_i for whatsit node created by pdfTeX 1598⟩ ≡

```

print("("); print_rule_dimen(pdf_height(p)); print_char("+"); print_rule_dimen(pdf_depth(p));
print(")x"); print_rule_dimen(pdf_width(p))

```

This code is used in sections 1600, 1600, and 1600.

1599. Each new type of node that appears in our data structure must be capable of being displayed, copied, destroyed, and so on. The routines that we need for write-oriented whatsits are somewhat like those for mark nodes; other extensions might, of course, involve more subtlety here.

⟨Basic printing procedures 57⟩ +≡

```
procedure print_write_whatsit(s : str_number; p : pointer);
  begin print_esc(s);
  if write_stream(p) < 16 then print_int(write_stream(p))
  else if write_stream(p) = 16 then print_char("*")
    else print_char("-");
  end;
```

1600. \langle Display the whatsit node *p* 1600 $\rangle \equiv$

```

case subtype(p) of
  open_node: begin print_write_whatsit("openout",p); print_char("=");
    print_file_name(open_name(p), open_area(p), open_ext(p));
  end;
  write_node: begin print_write_whatsit("write",p); print_mark(write_tokens(p));
  end;
  close_node: print_write_whatsit("closeout",p);
  special_node: begin print_esc("special"); print_mark(write_tokens(p));
  end;
  language_node: begin print_esc("setlanguage"); print_int(what_lang(p)); print("_(hyphenmin_");
    print_int(what_lhm(p)); print_char(","); print_int(what_rhm(p)); print_char(")");
  end;
  pdf_literal_node: begin print_esc("pdfliteral");
    case pdf_literal_mode(p) of
      set_origin: do_nothing;
      direct_page: print("_(page");
      direct_always: print("_(direct");
      othercases confusion("literal2")
    endcases; print_mark(pdf_literal_data(p));
  end;
  pdf_colorstack_node: begin print_esc("pdfcolorstack_"); print_int(pdf_colorstack_stack(p));
    case pdf_colorstack_cmd(p) of
      colorstack_set: print("_(set_");
      colorstack_push: print("_(push_");
      colorstack_pop: print("_(pop");
      colorstack_current: print("_(current");
      othercases confusion("pdfcolorstack")
    endcases;
    if pdf_colorstack_cmd(p) ≤ colorstack_data then print_mark(pdf_colorstack_data(p));
    end;
  pdf_setmatrix_node: begin print_esc("pdfsetmatrix"); print_mark(pdf_setmatrix_data(p));
  end;
  pdf_save_node: begin print_esc("pdfsave");
  end;
  pdf_restore_node: begin print_esc("pdfrestore");
  end;
  pdf_refobj_node: begin print_esc("pdfrefobj");
    if obj_obj_is_stream(pdf_obj_objnum(p)) > 0 then
      begin if obj_obj_stream_attr(pdf_obj_objnum(p)) ≠ null then
        begin print("_(attr"); print_mark(obj_obj_stream_attr(pdf_obj_objnum(p)));
        end;
        print("_(stream");
      end;
    if obj_obj_is_file(pdf_obj_objnum(p)) > 0 then print("_(file");
    print_mark(obj_obj_data(pdf_obj_objnum(p)));
  end;
  pdf_refxform_node: begin print_esc("pdfrefxform"); print("(");
    print_scaled(obj_xform_height(pdf_xform_objnum(p))); print_char("+");
    print_scaled(obj_xform_depth(pdf_xform_objnum(p))); print(")x");
    print_scaled(obj_xform_width(pdf_xform_objnum(p)));
  end;

```

```

pdf_refximage_node: begin print_esc("pdfrefximage"); print("(");
  print_scaled(obj_ximage_height(pdf_ximage_objnum(p))); print_char("+");
  print_scaled(obj_ximage_depth(pdf_ximage_objnum(p))); print("x");
  print_scaled(obj_ximage_width(pdf_ximage_objnum(p)));
end;
pdf_annot_node: begin print_esc("pdfannot");
  ⟨ Display rule speci for whatsit node created by pdfTeX 1598 ⟩;
  print_mark(pdf_annot_data(p));
end;
pdf_start_link_node: begin print_esc("pdfstartlink");
  ⟨ Display rule speci for whatsit node created by pdfTeX 1598 ⟩;
  if pdf_link_attr(p) ≠ null then
    begin print("_attr"); print_mark(pdf_link_attr(p));
    end;
  print("_action");
  if pdf_action_type(pdf_link_action(p)) = pdf_action_user then
    begin print("_user"); print_mark(pdf_action_user_tokens(pdf_link_action(p)));
    end
  else begin if pdf_action_file(pdf_link_action(p)) ≠ null then
    begin print("_file"); print_mark(pdf_action_file(pdf_link_action(p)));
    end;
  case pdf_action_type(pdf_link_action(p)) of
    pdf_action_goto: begin if pdf_action_named_id(pdf_link_action(p)) > 0 then
      begin print("_goto_name"); print_mark(pdf_action_id(pdf_link_action(p)));
      end
    else begin print("_goto_num"); print_int(pdf_action_id(pdf_link_action(p)));
    end;
  end;
  pdf_action_page: begin print("_page"); print_int(pdf_action_id(pdf_link_action(p)));
  print_mark(pdf_action_page_tokens(pdf_link_action(p)));
  end;
  pdf_action_thread: begin if pdf_action_named_id(pdf_link_action(p)) > 0 then
    begin print("_thread_name"); print_mark(pdf_action_id(pdf_link_action(p)));
    end
  else begin print("_thread_num"); print_int(pdf_action_id(pdf_link_action(p)));
  end;
  end;
  othercases pdf_error("displaying", "unknown_action_type");
  endcases;
end
end;
pdf_end_link_node: print_esc("pdfendlink");
pdf_dest_node: begin print_esc("pdfdest");
  if pdf_dest_named_id(p) > 0 then
    begin print("_name"); print_mark(pdf_dest_id(p));
    end
  else begin print("_num"); print_int(pdf_dest_id(p));
  end;
  print("_");
  case pdf_dest_type(p) of
    pdf_dest_xyz: begin print("xyz");
    if pdf_dest_xyz_zoom(p) ≠ null then

```



```

    begin print("\_zoom"); print_int(pdf_dest_xyz_zoom(p));
    end;
end;
pdf_dest_fitbh: print("fitbh");
pdf_dest_fitbv: print("fitbv");
pdf_dest_fitb: print("fitb");
pdf_dest_fith: print("fith");
pdf_dest_fitv: print("fitv");
pdf_dest_fitr: begin print("fitr"); { Display rule speci for whatsit node created by pdfTeX 1598 };
    end;
pdf_dest_fit: print("fit");
othercases print("unknown!");
endcases;
end;
pdf_thread_node, pdf_start_thread_node: begin if subtype(p) = pdf_thread_node then
    print_esc("pdfthread")
else print_esc("pdfstartthread");
    print("("); print_rule_dimen(pdf_height(p)); print_char("+"); print_rule_dimen(pdf_depth(p));
    print("x"); print_rule_dimen(pdf_width(p));
    if pdf_thread_attr(p) ≠ null then
        begin print("\_attr"); print_mark(pdf_thread_attr(p));
        end;
    if pdf_thread_named_id(p) > 0 then
        begin print("\_name"); print_mark(pdf_thread_id(p));
        end
    else begin print("\_num"); print_int(pdf_thread_id(p));
        end;
    end;
pdf_end_thread_node: print_esc("pdfendthread");
pdf_save_pos_node: print_esc("pdfsavepos");
pdf_snap_ref_point_node: print_esc("pdfsnaprefpoint");
pdf_snap_node: begin print_esc("pdfsnappy"); print_char("\_"); print_spec(snap_glue_ptr(p), 0);
    print_char("\_"); print_spec(final_skip(p), 0);
end;
pdf_snap_comp_node: begin print_esc("pdfsnappycomp"); print_char("\_");
    print_int(snap_comp_ratio(p));
end;
pdf_interword_space_on_node: print_esc("pdfinterwordspaceon");
pdf_interword_space_off_node: print_esc("pdfinterwordspaceoff");
pdf_fake_space_node: print_esc("pdffakespace");
pdf_running_link_off_node: print_esc("pdfrunninglinkoff");
pdf_running_link_on_node: print_esc("pdfrunninglinkon");
othercases print("whatsit?")
endcases

```

This code is used in section 201.

1601. \langle Make a partial copy of the whatsit node p and make r point to it; set $words$ to the number of initial words not yet copied 1601 $\rangle \equiv$

```

case subtype( $p$ ) of
  open_node: begin  $r \leftarrow get\_node(open\_node\_size)$ ;  $words \leftarrow open\_node\_size$ ;
    end;
  write_node, special_node: begin  $r \leftarrow get\_node(write\_node\_size)$ ;  $add\_token\_ref(write\_tokens(p))$ ;
     $words \leftarrow write\_node\_size$ ;
    end;
  close_node, language_node: begin  $r \leftarrow get\_node(small\_node\_size)$ ;  $words \leftarrow small\_node\_size$ ;
    end;
  pdf_literal_node: begin  $r \leftarrow get\_node(write\_node\_size)$ ;  $add\_token\_ref(pdf\_literal\_data(p))$ ;
     $words \leftarrow write\_node\_size$ ;
    end;
  pdf_colorstack_node: begin if  $pdf\_colorstack\_cmd(p) \leq colorstack\_data$  then
    begin  $r \leftarrow get\_node(pdf\_colorstack\_setter\_node\_size)$ ;  $add\_token\_ref(pdf\_colorstack\_data(p))$ ;
       $words \leftarrow pdf\_colorstack\_setter\_node\_size$ ;
    end
    else begin  $r \leftarrow get\_node(pdf\_colorstack\_getter\_node\_size)$ ;  $words \leftarrow pdf\_colorstack\_getter\_node\_size$ ;
      end;
    end;
  pdf_setmatrix_node: begin  $r \leftarrow get\_node(pdf\_setmatrix\_node\_size)$ ;  $add\_token\_ref(pdf\_setmatrix\_data(p))$ ;
     $words \leftarrow pdf\_setmatrix\_node\_size$ ;
    end;
  pdf_save_node: begin  $r \leftarrow get\_node(pdf\_save\_node\_size)$ ;  $words \leftarrow pdf\_save\_node\_size$ ;
    end;
  pdf_restore_node: begin  $r \leftarrow get\_node(pdf\_restore\_node\_size)$ ;  $words \leftarrow pdf\_restore\_node\_size$ ;
    end;
  pdf_refobj_node: begin  $r \leftarrow get\_node(pdf\_refobj\_node\_size)$ ;  $words \leftarrow pdf\_refobj\_node\_size$ ;
    end;
  pdf_refxform_node: begin  $r \leftarrow get\_node(pdf\_refxform\_node\_size)$ ;  $words \leftarrow pdf\_refxform\_node\_size$ ;
    end;
  pdf_refximage_node: begin  $r \leftarrow get\_node(pdf\_refximage\_node\_size)$ ;  $words \leftarrow pdf\_refximage\_node\_size$ ;
    end;
  pdf_annot_node: begin  $r \leftarrow get\_node(pdf\_annot\_node\_size)$ ;  $add\_token\_ref(pdf\_annot\_data(p))$ ;
     $words \leftarrow pdf\_annot\_node\_size$ ;
    end;
  pdf_start_link_node: begin  $r \leftarrow get\_node(pdf\_annot\_node\_size)$ ;  $pdf\_height(r) \leftarrow pdf\_height(p)$ ;
     $pdf\_depth(r) \leftarrow pdf\_depth(p)$ ;  $pdf\_width(r) \leftarrow pdf\_width(p)$ ;  $pdf\_link\_attr(r) \leftarrow pdf\_link\_attr(p)$ ;
    if  $pdf\_link\_attr(r) \neq null$  then  $add\_token\_ref(pdf\_link\_attr(r))$ ;
     $pdf\_link\_action(r) \leftarrow pdf\_link\_action(p)$ ;  $add\_action\_ref(pdf\_link\_action(r))$ ;
     $pdf\_link\_objnum(r) \leftarrow pdf\_link\_objnum(p)$ ;
    end;
  pdf_end_link_node:  $r \leftarrow get\_node(small\_node\_size)$ ;
  pdf_dest_node: begin  $r \leftarrow get\_node(pdf\_dest\_node\_size)$ ;
    if  $pdf\_dest\_named\_id(p) > 0$  then  $add\_token\_ref(pdf\_dest\_id(p))$ ;
     $words \leftarrow pdf\_dest\_node\_size$ ;
    end;
  pdf_thread_node, pdf_start_thread_node: begin  $r \leftarrow get\_node(pdf\_thread\_node\_size)$ ;
    if  $pdf\_thread\_named\_id(p) > 0$  then  $add\_token\_ref(pdf\_thread\_id(p))$ ;
    if  $pdf\_thread\_attr(p) \neq null$  then  $add\_token\_ref(pdf\_thread\_attr(p))$ ;
     $words \leftarrow pdf\_thread\_node\_size$ ;
    end;

```

```

pdf_end_thread_node: r ← get_node(small_node_size);
pdf_save_pos_node: r ← get_node(small_node_size);
pdf_snap_ref_point_node: r ← get_node(small_node_size);
pdf_snap_node: begin add_glue_ref(snap_glue_ptr(p)); r ← get_node(snap_node_size);
    words ← snap_node_size;
end;
pdf_snap_comp_node: r ← get_node(small_node_size);
pdf_interword_space_on_node: r ← get_node(small_node_size);
pdf_interword_space_off_node: r ← get_node(small_node_size);
pdf_fake_space_node: r ← get_node(small_node_size);
pdf_running_link_off_node: r ← get_node(small_node_size);
pdf_running_link_on_node: r ← get_node(small_node_size);
othercases confusion("ext2")
endcases

```

This code is used in sections [224](#) and [1730](#).

1602. \langle Wipe out the whatsit node p and **goto** *done* 1602 $\rangle \equiv$

```

begin case subtype( $p$ ) of
  open_node: free_node( $p$ , open_node_size);
  write_node, special_node: begin delete_token_ref(write_tokens( $p$ )); free_node( $p$ , write_node_size);
    goto done;
  end;
  close_node, language_node: free_node( $p$ , small_node_size);
  pdf_literal_node: begin delete_token_ref(pdf_literal_data( $p$ )); free_node( $p$ , write_node_size);
    end;
  pdf_colorstack_node: begin if pdf_colorstack_cmd( $p$ )  $\leq$  colorstack_data then
    begin delete_token_ref(pdf_colorstack_data( $p$ )); free_node( $p$ , pdf_colorstack_setter_node_size);
    end
  else free_node( $p$ , pdf_colorstack_getter_node_size);
  end;
  pdf_setmatrix_node: begin delete_token_ref(pdf_setmatrix_data( $p$ )); free_node( $p$ , pdf_setmatrix_node_size);
    end;
  pdf_save_node: begin free_node( $p$ , pdf_save_node_size);
    end;
  pdf_restore_node: begin free_node( $p$ , pdf_restore_node_size);
    end;
  pdf_refobj_node: free_node( $p$ , pdf_refobj_node_size);
  pdf_refxform_node: free_node( $p$ , pdf_refxform_node_size);
  pdf_refximage_node: free_node( $p$ , pdf_refximage_node_size);
  pdf_annot_node: begin delete_token_ref(pdf_annot_data( $p$ )); free_node( $p$ , pdf_annot_node_size);
    end;
  pdf_start_link_node: begin if pdf_link_attr( $p$ )  $\neq$  null then delete_token_ref(pdf_link_attr( $p$ ));
    delete_action_ref(pdf_link_action( $p$ )); free_node( $p$ , pdf_annot_node_size);
  end;
  pdf_end_link_node: free_node( $p$ , small_node_size);
  pdf_dest_node: begin if pdf_dest_named_id( $p$ )  $>$  0 then delete_token_ref(pdf_dest_id( $p$ ));
    free_node( $p$ , pdf_dest_node_size);
  end;
  pdf_thread_node, pdf_start_thread_node: begin if pdf_thread_named_id( $p$ )  $>$  0 then
    delete_token_ref(pdf_thread_id( $p$ ));
    if pdf_thread_attr( $p$ )  $\neq$  null then delete_token_ref(pdf_thread_attr( $p$ ));
    free_node( $p$ , pdf_thread_node_size);
  end;
  pdf_end_thread_node: free_node( $p$ , small_node_size);
  pdf_save_pos_node: free_node( $p$ , small_node_size);
  pdf_snap_ref_point_node: free_node( $p$ , small_node_size);
  pdf_snapy_node: begin delete_glue_ref(snap_glue_ptr( $p$ )); free_node( $p$ , snap_node_size);
    end;
  pdf_snapy_comp_node: free_node( $p$ , small_node_size);
  pdf_interword_space_on_node: free_node( $p$ , small_node_size);
  pdf_interword_space_off_node: free_node( $p$ , small_node_size);
  pdf_fake_space_node: free_node( $p$ , small_node_size);
  pdf_running_link_off_node: free_node( $p$ , small_node_size);
  pdf_running_link_on_node: free_node( $p$ , small_node_size);
othercases confusion("ext3")
endcases;
goto done;
end

```

This code is used in section 220.

1603. \langle Incorporate a whatsit node into a vbox 1603 $\rangle \equiv$
if (*subtype*(*p*) = *pdf_refxform_node*) \vee (*subtype*(*p*) = *pdf_refximage_node*) **then**
 begin *x* \leftarrow *x* + *d* + *pdf_height*(*p*); *d* \leftarrow *pdf_depth*(*p*); *s* \leftarrow 0;
 if *pdf_width*(*p*) + *s* > *w* **then** *w* \leftarrow *pdf_width*(*p*) + *s*;
 end

This code is used in section 843.

1604. \langle Incorporate a whatsit node into an hbox 1604 $\rangle \equiv$
if (*subtype*(*p*) = *pdf_refxform_node*) \vee (*subtype*(*p*) = *pdf_refximage_node*) **then**
 begin *x* \leftarrow *x* + *pdf_width*(*p*); *s* \leftarrow 0;
 if *pdf_height*(*p*) - *s* > *h* **then** *h* \leftarrow *pdf_height*(*p*) - *s*;
 if *pdf_depth*(*p*) + *s* > *d* **then** *d* \leftarrow *pdf_depth*(*p*) + *s*;
 end

This code is used in section 823.

1605. \langle Let *d* be the width of the whatsit *p* 1605 $\rangle \equiv$
if (*subtype*(*p*) = *pdf_refxform_node*) \vee (*subtype*(*p*) = *pdf_refximage_node*) **then** *d* \leftarrow *pdf_width*(*p*)
else *d* \leftarrow 0

This code is used in section 1323.

1606. **define** *adv_past*(#) \equiv **if** *subtype*(#) = *language_node* **then**
 begin *cur_lang* \leftarrow *what_lang*(#); *L_hyf* \leftarrow *what_lhm*(#); *r_hyf* \leftarrow *what_rhm*(#); **end**

\langle Advance past a whatsit node in the *line_break* loop 1606 $\rangle \equiv$ **begin** *adv_past*(*cur_p*);
if (*subtype*(*cur_p*) = *pdf_refxform_node*) \vee (*subtype*(*cur_p*) = *pdf_refximage_node*) **then**
 act_width \leftarrow *act_width* + *pdf_width*(*cur_p*);
end

This code is used in section 1040.

1607. \langle Advance past a whatsit node in the pre-hyphenation loop 1607 $\rangle \equiv$ **if** *subtype*(*s*) = *language_node*
then
 begin *cur_lang* \leftarrow *what_lang*(*s*); *L_hyf* \leftarrow *what_lhm*(*s*); *r_hyf* \leftarrow *what_rhm*(*s*); *set_hyph_index*;
 end

This code is used in section 1071.

1608. \langle Prepare to move whatsit *p* to the current page, then **goto** *contribute* 1608 $\rangle \equiv$
begin **if** (*subtype*(*p*) = *pdf_refxform_node*) \vee (*subtype*(*p*) = *pdf_refximage_node*) **then**
 begin *page_total* \leftarrow *page_total* + *page_depth* + *pdf_height*(*p*); *page_depth* \leftarrow *pdf_depth*(*p*);
 end;
goto *contribute*;
end

This code is used in section 1175.

1609. \langle Process whatsit *p* in *vert_break* loop, **goto** *not_found* 1609 $\rangle \equiv$
begin **if** (*subtype*(*p*) = *pdf_refxform_node*) \vee (*subtype*(*p*) = *pdf_refximage_node*) **then**
 begin *cur_height* \leftarrow *cur_height* + *prev_dp* + *pdf_height*(*p*); *prev_dp* \leftarrow *pdf_depth*(*p*);
 end;
goto *not_found*;
end

This code is used in section 1148.

1610. \langle Output the whatsit node p in a vlist 1610 $\rangle \equiv$
 $out_what(p)$

This code is used in section 659.

1611. \langle Output the whatsit node p in an hlist 1611 $\rangle \equiv$
 $out_what(p)$

This code is used in section 650.

1612. After all this preliminary shuffling, we come finally to the routines that actually send out the requested data. Let's do `\special` first (it's easier).

\langle Declare procedures needed in *hlist_out*, *vlist_out* 1612 $\rangle \equiv$

```
procedure special_out( $p$  : pointer);
  var old_setting : 0 .. max_selector; { holds print selector }
      k : pool_pointer; { index into str_pool }
  begin synch_h; synch_v;
  old_setting  $\leftarrow$  selector; selector  $\leftarrow$  new_string;
  show_token_list(link(write_tokens( $p$ )), null, pool_size - pool_ptr); selector  $\leftarrow$  old_setting; str_room(1);
  if cur_length < 256 then
    begin dvi_out(xxx1); dvi_out(cur_length);
    end
  else begin dvi_out(xxx4); dvi_four(cur_length);
    end;
  for  $k \leftarrow$  str_start[str_ptr] to pool_ptr - 1 do dvi_out(so(str_pool[k]));
  pool_ptr  $\leftarrow$  str_start[str_ptr]; { erase the string }
  end;
```

See also sections 1614, 1617, 1716, and 1720.

This code is used in section 647.

1613. To write a token list, we must run it through T_EX's scanner, expanding macros and `\the` and `\number`, etc. This might cause runaways, if a delimited macro parameter isn't matched, and runaways would be extremely confusing since we are calling on T_EX's scanner in the middle of a `\shipout` command. Therefore we will put a dummy control sequence as a "stopper," right after the token list. This control sequence is artificially defined to be `\outer`.

\langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$

```
text(end_write)  $\leftarrow$  "endwrite"; eq_level(end_write)  $\leftarrow$  level_one; eq_type(end_write)  $\leftarrow$  outer_call;
equiv(end_write)  $\leftarrow$  null;
```

1614. \langle Declare procedures needed in *hlist_out*, *vlist_out* 1612 $\rangle + \equiv$

```
procedure write_out(p : pointer);
  var old_setting: 0 .. max_selector; { holds print selector }
      old_mode: integer; { saved mode }
      j: small_number; { write stream number }
      q, r: pointer; { temporary variables for list manipulation }
begin  $\langle$  Expand macros in the token list and make link(def_ref) point to the result 1615  $\rangle$ ;
  old_setting  $\leftarrow$  selector; j  $\leftarrow$  write_stream(p);
  if write_open[j] then selector  $\leftarrow$  j
else begin { write to the terminal if file isn't open }
    if (j = 17)  $\wedge$  (selector = term_and_log) then selector  $\leftarrow$  log_only;
    print_nl("");
  end;
  token_show(def_ref); print_ln; flush_list(def_ref); selector  $\leftarrow$  old_setting;
end;
```

1615. The final line of this routine is slightly subtle; at least, the author didn't think about it until getting burnt! There is a used-up token list on the stack, namely the one that contained *end_write_token*. (We insert this artificial '*\endwrite*' to prevent runaways, as explained above.) If it were not removed, and if there were numerous writes on a single page, the stack would overflow.

```
define end_write_token  $\equiv$  cs_token_flag + end_write
 $\langle$  Expand macros in the token list and make link(def_ref) point to the result 1615  $\rangle \equiv$ 
  q  $\leftarrow$  get_avail; info(q)  $\leftarrow$  right_brace_token + "}";
  r  $\leftarrow$  get_avail; link(q)  $\leftarrow$  r; info(r)  $\leftarrow$  end_write_token; ins_list(q);
  begin_token_list(write_tokens(p), write_text);
  q  $\leftarrow$  get_avail; info(q)  $\leftarrow$  left_brace_token + "{"; ins_list(q);
  { now we're ready to scan '\{token list\} \endwrite' }
  old_mode  $\leftarrow$  mode; mode  $\leftarrow$  0; { disable \prevdepth, \spacefactor, \lastskip, \prevgraf }
  cur_cs  $\leftarrow$  write_loc; q  $\leftarrow$  scan_toks(false, true); { expand macros, etc. }
  get_token; if cur_tok  $\neq$  end_write_token then  $\langle$  Recover from an unbalanced write command 1616  $\rangle$ ;
  mode  $\leftarrow$  old_mode; end_token_list { conserve stack space }
```

This code is used in section 1614.

1616. \langle Recover from an unbalanced write command 1616 $\rangle \equiv$

```
begin print_err("Unbalanced_write_command");
  help2("On this page there's a \write with fewer real {s than}s.")
  ("I can't handle that very well; good luck."); error;
repeat get_token;
until cur_tok = end_write_token;
end
```

This code is used in section 1615.

1617. The *out_what* procedure takes care of outputting whatsit nodes for *vlist_out* and *hlist_out*.

⟨Declare procedures needed in *hlist_out*, *vlist_out* 1612⟩ +≡

```
procedure out_what(p : pointer);
  var j: small_number; { write stream number }
  begin case subtype(p) of
    open_node, write_node, close_node: ⟨Do some work that has been queued up for \write 1619⟩;
    special_node: special_out(p);
    language_node: do_nothing;
    pdf_save_pos_node: ⟨Save current position in DVI mode 1618⟩;
    others: begin if (pdfTeX_first_extension_code ≤ subtype(p)) ∧ (subtype(p) ≤ pdfTeX_last_extension_code)
      then pdf_error("ext4", "pdf_node_ended_up_in_DVI_mode")
    else confusion("ext4")
    end;
  endcases;
end;
```

1618. ⟨Save current position in DVI mode 1618⟩ ≡

```
begin { 4736286 = 1in, the funny DVI origin offset }
  pdf_last_x_pos ← cur_h + 4736286; pdf_last_y_pos ← cur_page_height - cur_v - 4736286;
end
```

This code is used in section 1617.

1619. We don't implement \write inside of leaders. (The reason is that the number of times a leader box appears might be different in different implementations, due to machine-dependent rounding in the glue calculations.)

⟨Do some work that has been queued up for \write 1619⟩ ≡

```
if ¬doing_leaders then
  begin j ← write_stream(p);
  if subtype(p) = write_node then write_out(p)
  else begin if write_open[j] then a_close(write_file[j]);
    if subtype(p) = close_node then write_open[j] ← false
  else if j < 16 then
    begin cur_name ← open_name(p); cur_area ← open_area(p); cur_ext ← open_ext(p);
    if cur_ext = "" then cur_ext ← ".tex";
    pack_cur_name;
    while ¬a_open_out(write_file[j]) do prompt_file_name("output_file_name", ".tex");
    write_open[j] ← true;
    end;
  end;
end
```

This code is used in section 1617.

1620. The presence of ‘\immediate’ causes the *do_extension* procedure to descend to one level of recursion. Nothing happens unless \immediate is followed by ‘\openout’, ‘\write’, or ‘\closeout’.

⟨Implement \immediate 1620⟩ ≡

```

begin get_x_token;
if cur_cmd = extension then
  begin if cur_chr ≤ close_node then
    begin p ← tail; do_extension; { append a whatsit node }
    out_what(tail); { do the action immediately }
    flush_node_list(tail); tail ← p; link(p) ← null;
  end
  else case cur_chr of
    pdf_obj_code: begin do_extension; { scan object and set pdf_last_obj }
      if obj_data_ptr(pdf_last_obj) = 0 then { this object has not been initialized yet }
        pdf_error("ext1", "\pdfobj\reserveobjnum\ cannot be used with \immediate");
        pdf_write_obj(pdf_last_obj);
      end;
    pdf_xform_code: begin do_extension; { scan form and set pdf_last_xform }
      pdf_cur_form ← pdf_last_xform; pdf_ship_out(obj_xform_box(pdf_last_xform), false);
    end;
    pdf_ximage_code: begin do_extension; { scan image and set pdf_last_ximage }
      pdf_write_image(pdf_last_ximage);
    end;
    othercases back_input
  endcases;
end
else back_input;
end

```

This code is used in section 1526.

1621. The \language extension is somewhat different. We need a subroutine that comes into play when a character of a non-clang language is being appended to the current paragraph.

⟨Declare action procedures for use by *main_control* 1219⟩ +≡

```

procedure fix_language;
  var l: ASCII_code; { the new current language }
  begin if language ≤ 0 then l ← 0
  else if language > 255 then l ← 0
    else l ← language;
  if l ≠ clang then
    begin new_whatsit(language_node, small_node_size); what_lang(tail) ← l; clang ← l;
    what_lhm(tail) ← norm_min(left_hyphen_min); what_rhm(tail) ← norm_min(right_hyphen_min);
    end;
  end;

```

1622. $\langle \text{Implement } \backslash\text{setlanguage } 1622 \rangle \equiv$
if $\text{abs}(\text{mode}) \neq \text{hmode}$ **then** $\text{report_illegal_case}$
else begin $\text{new_whatsit}(\text{language_node}, \text{small_node_size}); \text{scan_int};$
if $\text{cur_val} \leq 0$ **then** $\text{clang} \leftarrow 0$
else if $\text{cur_val} > 255$ **then** $\text{clang} \leftarrow 0$
else $\text{clang} \leftarrow \text{cur_val};$
 $\text{what_lang}(\text{tail}) \leftarrow \text{clang}; \text{what_lhm}(\text{tail}) \leftarrow \text{norm_min}(\text{left_hyphen_min});$
 $\text{what_rh}(\text{tail}) \leftarrow \text{norm_min}(\text{right_hyphen_min});$
end

This code is used in section 1526.

1623. $\langle \text{Finish the extensions } 1623 \rangle \equiv$
for $k \leftarrow 0$ **to** 15 **do**
if $\text{write_open}[k]$ **then** $\text{a_close}(\text{write_file}[k])$

This code is used in section 1511.

1624. Shipping out PDF marks.

$\langle \text{Types in the outer block } 18 \rangle + \equiv$
 $\text{dest_name_entry} = \text{record } \text{objname: } \text{str_number}; \quad \{ \text{destination name} \}$
 $\text{objnum: } \text{integer}; \quad \{ \text{destination object number} \}$
end;

1625. \langle Global variables 13 $\rangle + \equiv$

cur_page_width: scaled; { width of page being shipped }
cur_page_height: scaled; { height of page being shipped }
cur_h_offset: scaled; { horizontal offset of page being shipped }
cur_v_offset: scaled; { vertical offset of page being shipped }
pdf_obj_list: pointer; { list of objects in the current page }
pdf_xform_list: pointer; { list of forms in the current page }
pdf_ximage_list: pointer; { list of images in the current page }
last_thread: pointer; { pointer to the last thread }
pdf_thread_ht, *pdf_thread_dp*, *pdf_thread_wd*: scaled; { dimensions of the last thread }
pdf_last_thread_id: halfword; { identifier of the last thread }
pdf_last_thread_named_id: boolean; { is identifier of the last thread named }
pdf_thread_level: integer; { depth of nesting of box containing the last thread }
pdf_annot_list: pointer; { list of annotations in the current page }
pdf_link_list: pointer; { list of link annotations in the current page }
pdf_dest_list: pointer; { list of destinations in the current page }
pdf_bead_list: pointer; { list of thread beads in the current page }
pdf_obj_count: integer; { counter of objects }
pdf_xform_count: integer; { counter of forms }
pdf_ximage_count: integer; { counter of images }
pdf_cur_form: integer; { the form being output }
pdf_first_outline, *pdf_last_outline*, *pdf_parent_outline*: integer;
pdf_xform_width, *pdf_xform_height*, *pdf_xform_depth*: scaled; { dimension of the current form }
pdf_info_toks: pointer; { additional keys of Info dictionary }
pdf_catalog_toks: pointer; { additional keys of Catalog dictionary }
pdf_catalog_openaction: integer;
pdf_names_toks: pointer; { additional keys of Names dictionary }
pdf_dest_names_ptr: integer; { first unused position in *dest_names* }
dest_names_size: integer; { maximum number of names in name tree of PDF output file }
dest_names: \uparrow *dest_name_entry*;
pk_dpi: integer; { PK pixel density value from *texmf.cnf* }
image_orig_x, *image_orig_y*: integer; { origin of cropped PDF images }
pdf_trailer_toks: pointer; { additional keys of Trailer dictionary }
pdf_trailer_id_toks: pointer; { custom Trailer ID }
gen_faked_interword_space: boolean; { flag to turn on/off faked interword spaces }
gen_running_link: boolean; { flag to turn on/off running link }

1626. \langle Set initial values of key variables 21 $\rangle + \equiv$

pdf_first_outline \leftarrow 0; *pdf_last_outline* \leftarrow 0; *pdf_parent_outline* \leftarrow 0; *pdf_obj_count* \leftarrow 0;
pdf_xform_count \leftarrow 0; *pdf_ximage_count* \leftarrow 0; *pdf_dest_names_ptr* \leftarrow 0; *pdf_info_toks* \leftarrow null;
pdf_catalog_toks \leftarrow null; *pdf_names_toks* \leftarrow null; *pdf_catalog_openaction* \leftarrow 0; *pdf_trailer_toks* \leftarrow null;
pdf_trailer_id_toks \leftarrow null; *gen_faked_interword_space* \leftarrow false; *gen_running_link* \leftarrow true;

1627. The following procedures are needed for outputting whatsit nodes for pdfTeX.

```

(Declare procedures needed in pdf_hlist_out, pdf_vlist_out 727) +≡
procedure write_action(p : pointer); { write an action specification }
  var s : str_number; d : integer;
  begin if pdf_action_type(p) = pdf_action_user then
    begin pdf_print_toks_ln(pdf_action_user_tokens(p)); return;
    end;
  pdf_print("<<");
  if pdf_action_file(p) ≠ null then
    begin pdf_print("/F"); s ← tokens_to_string(pdf_action_file(p));
    if (str_pool[str_start[s]] = 40) ∧ (str_pool[str_start[s] + length(s) - 1] = 41) then pdf_print(s)
    else begin pdf_print_str(s);
      end;
    flush_str(s); pdf_print("");
    if pdf_action_new_window(p) > 0 then
      begin pdf_print("/NewWindow");
      if pdf_action_new_window(p) = 1 then pdf_print("true")
      else pdf_print("false");
      end;
    end;
  case pdf_action_type(p) of
    pdf_action_page: begin if pdf_action_file(p) = null then
      begin pdf_print("/S/GoTo/D"); pdf_print_int(get_obj(obj_type_page, pdf_action_id(p), false));
      pdf_print("O_R");
      end
    else begin pdf_print("/S/GoToR/D"); pdf_print_int(pdf_action_id(p) - 1);
      end;
    pdf_out(""); pdf_print(tokens_to_string(pdf_action_page_tokens(p))); flush_str(last_tokens_string);
    pdf_out("");
    end;
    pdf_action_goto: begin if pdf_action_file(p) = null then
      begin pdf_print("/S/GoTo"); d ← get_obj(obj_type_dest, pdf_action_id(p), pdf_action_named_id(p));
      end
    else pdf_print("/S/GoToR");
    if pdf_action_named_id(p) > 0 then
      begin pdf_str_entry("D", tokens_to_string(pdf_action_id(p))); flush_str(last_tokens_string);
      end
    else if pdf_action_file(p) = null then pdf_indirect("D", d)
      else pdf_error("ext4", "`goto` option cannot be used with both `file` and `num`");
    end;
    pdf_action_thread: begin pdf_print("/S/Thread");
    if pdf_action_file(p) = null then
      d ← get_obj(obj_type_thread, pdf_action_id(p), pdf_action_named_id(p));
    if pdf_action_named_id(p) > 0 then
      begin pdf_str_entry("D", tokens_to_string(pdf_action_id(p))); flush_str(last_tokens_string);
      end
    else if pdf_action_file(p) = null then pdf_indirect("D", d)
      else pdf_int_entry("D", pdf_action_id(p));
    end;
  endcases; pdf_print_ln(">>");
  end;
procedure set_rect_dimens(p, parent_box : pointer; x, y, w, h, d, margin : scaled);

```

```

begin pdf_left(p) ← cur_h;
if is_running(w) then pdf_right(p) ← x + width(parent_box)
else pdf_right(p) ← cur_h + w;
if is_running(h) then pdf_top(p) ← y - height(parent_box)
else pdf_top(p) ← cur_v - h;
if is_running(d) then pdf_bottom(p) ← y + depth(parent_box)
else pdf_bottom(p) ← cur_v + d;
if is_shipping_page ∧ matrixused then
  begin matrixtransformrect(pdf_left(p), cur_page_height - pdf_bottom(p), pdf_right(p),
    cur_page_height - pdf_top(p)); pdf_left(p) ← getllx; pdf_bottom(p) ← cur_page_height - getlly;
    pdf_right(p) ← geturx; pdf_top(p) ← cur_page_height - getury;
  end;
pdf_left(p) ← pdf_left(p) - margin; pdf_top(p) ← pdf_top(p) - margin;
pdf_right(p) ← pdf_right(p) + margin; pdf_bottom(p) ← pdf_bottom(p) + margin;
end;
procedure do_annot(p, parent_box : pointer; x, y : scaled);
  begin if ¬is_shipping_page then pdf_error("ext4", "annotations cannot be inside an XForm");
  if doing_leaders then return;
  if is_obj_scheduled(pdf_annot_objnum(p)) then pdf_annot_objnum(p) ← pdf_new_objnum;
  set_rect_dimens(p, parent_box, x, y, pdf_width(p), pdf_height(p), pdf_depth(p), 0);
  obj_annot_ptr(pdf_annot_objnum(p)) ← p; pdf_append_list(pdf_annot_objnum(p))(pdf_annot_list);
  set_obj_scheduled(pdf_annot_objnum(p));
  end;

```

1628. To implement nested link annotations, we need a stack to hold copy of *pdf_start_link_node*'s that are being written out, together with their box nesting level.

```

define pdf_link_stack_top ≡ pdf_link_stack[pdf_link_stack_ptr]
⟨ Constants in the outer block 11 ⟩ +≡
  pdf_max_link_level = 10; { maximum depth of link nesting }

```

1629. ⟨ Types in the outer block 18 ⟩ +≡
pdf_link_stack_record = **record** nesting_level: integer;
 link_node: pointer; { holds a copy of the corresponding *pdf_start_link_node* }
 ref_link_node: pointer; { points to original *pdf_start_link_node*, or a copy of *link_node* created by
 append_link in case of multi-line link }
end;

1630. ⟨ Global variables 13 ⟩ +≡
pdf_link_stack: **array** [1 .. pdf_max_link_level] **of** *pdf_link_stack_record*;
pdf_link_stack_ptr: small_number;

1631. ⟨ Set initial values of key variables 21 ⟩ +≡
pdf_link_stack_ptr ← 0;

1632. \langle Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727 $\rangle + \equiv$

```

procedure push_link_level(p : pointer);
  begin if pdf_link_stack_ptr  $\geq$  pdf_max_link_level then
    overflow("pdf_link_stack_size", pdf_max_link_level);
    pdfassert((type(p) = whatsit_node)  $\wedge$  (subtype(p) = pdf_start_link_node)); incr(pdf_link_stack_ptr);
    pdf_link_stack_top.nesting_level  $\leftarrow$  cur_s; pdf_link_stack_top.link_node  $\leftarrow$  copy_node_list(p);
    pdf_link_stack_top.ref_link_node  $\leftarrow$  p;
  end;

procedure pop_link_level;
  begin pdfassert(pdf_link_stack_ptr > 0); flush_node_list(pdf_link_stack_top.link_node);
  decr(pdf_link_stack_ptr);
end;

procedure do_link(p, parent_box : pointer; x, y : scaled);
  begin if  $\neg$ is_shipping_page then
    pdf_error("ext4", "link_annotations_cannot_be_inside_an_XForm");
    pdfassert(type(parent_box) = hlist_node);
    if is_obj_scheduled(pdf_link_objnum(p)) then pdf_link_objnum(p)  $\leftarrow$  pdf_new_objnum;
    push_link_level(p);
    set_rect_dimens(p, parent_box, x, y, pdf_width(p), pdf_height(p), pdf_depth(p), pdf_link_margin);
    obj_annot_ptr(pdf_link_objnum(p))  $\leftarrow$  p; { the reference for the pdf annot object must be set here }
    pdf_append_list(pdf_link_objnum(p))(pdf_link_list); set_obj_scheduled(pdf_link_objnum(p));
  end;

procedure end_link;
  var p: pointer;
  begin if pdf_link_stack_ptr < 1 then
    pdf_error("ext4", "pdf_link_stack_empty, \pdfendlink used without \pdfstartlink?");
  if pdf_link_stack_top.nesting_level  $\neq$  cur_s then pdf_warning(0,
    "\pdfendlink ended up in different nesting level than \pdfstartlink", true, true);
    { N.B.: test for running link must be done on link_node and not ref_link_node, as ref_link_node can
      be set by do_link or append_link already }
  if is_running(pdf_width(pdf_link_stack_top.link_node)) then
    begin p  $\leftarrow$  pdf_link_stack_top.ref_link_node;
    if is_shipping_page  $\wedge$  matrixused then
      begin matrixrecalculate(cur_h + pdf_link_margin); pdf_left(p)  $\leftarrow$  getllx - pdf_link_margin;
      pdf_top(p)  $\leftarrow$  cur_page_height - getury - pdf_link_margin; pdf_right(p)  $\leftarrow$  geturx + pdf_link_margin;
      pdf_bottom(p)  $\leftarrow$  cur_page_height - getlly + pdf_link_margin;
      end
    else pdf_right(p)  $\leftarrow$  cur_h + pdf_link_margin;
    end;
  pop_link_level;
end;

```

1633. For “running” annotations we must append a new node when the end of annotation is in other box than its start. The new created node is identical to corresponding *whatsit* node representing the start of annotation, but its *info* field is *max_halfword*. We set *info* field just before destroying the node, in order to use *flush_node_list* to do the job.

⟨ Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727 ⟩ +≡

```
procedure append_link(parent_box : pointer; x, y : scaled; i : small_number);
    { append a new pdf annot to pdf_link_list }
var p: pointer;
begin pdfassert(type(parent_box) = hlist_node); p ← copy_node_list(pdf_link_stack[i].link_node);
pdf_link_stack[i].ref_link_node ← p; info(p) ← max_halfword;
    { mark that this node is not a whatsit node }
link(p) ← null; { this node is not linked in any list }
set_rect_dimens(p, parent_box, x, y, pdf_width(p), pdf_height(p), pdf_depth(p), pdf_link_margin);
pdf_create_obj(obj_type_others, 0); obj_annot_ptr(obj_ptr) ← p; pdf_append_list(obj_ptr)(pdf_link_list);
end;
```

1634. Threads are handled in similar way as link annotations.

(Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727) +≡

```

procedure append_bead(p : pointer);
  var a, b, c, t: integer;
  begin if  $\neg$ is_shipping_page then pdf_error("ext4", "threads_cannot_be_inside_an_XForm");
  t  $\leftarrow$  get_obj(obj_type_thread, pdf_thread_id(p), pdf_thread_named_id(p)); b  $\leftarrow$  pdf_new_objnum;
  obj_bead_ptr(b)  $\leftarrow$  pdf_get_mem(pdfmem_bead_size); obj_bead_page(b)  $\leftarrow$  pdf_last_page;
  obj_bead_data(b)  $\leftarrow$  p;
  if pdf_thread_attr(p)  $\neq$  null then obj_bead_attr(b)  $\leftarrow$  tokens_to_string(pdf_thread_attr(p))
  else obj_bead_attr(b)  $\leftarrow$  0;
  if obj_thread_first(t) = 0 then
    begin obj_thread_first(t)  $\leftarrow$  b; obj_bead_next(b)  $\leftarrow$  b; obj_bead_prev(b)  $\leftarrow$  b;
    end
  else begin a  $\leftarrow$  obj_thread_first(t); c  $\leftarrow$  obj_bead_prev(a); obj_bead_prev(b)  $\leftarrow$  c; obj_bead_next(b)  $\leftarrow$  a;
    obj_bead_prev(a)  $\leftarrow$  b; obj_bead_next(c)  $\leftarrow$  b;
    end;
  pdf_append_list(b)(pdf_bead_list);
  end;

procedure do_thread(p, parent_box : pointer; x, y : scaled);
  begin if doing_leaders then return;
  if subtype(p) = pdf_start_thread_node then
    begin pdf_thread_wd  $\leftarrow$  pdf_width(p); pdf_thread_ht  $\leftarrow$  pdf_height(p); pdf_thread_dp  $\leftarrow$  pdf_depth(p);
    pdf_last_thread_id  $\leftarrow$  pdf_thread_id(p); pdf_last_thread_named_id  $\leftarrow$  (pdf_thread_named_id(p) > 0);
    if pdf_last_thread_named_id then add_token_ref(pdf_thread_id(p));
    pdf_thread_level  $\leftarrow$  cur_s;
    end;
    set_rect_dimens(p, parent_box, x, y, pdf_width(p), pdf_height(p), pdf_depth(p), pdf_thread_margin);
    append_bead(p); last_thread  $\leftarrow$  p;
  end;

procedure append_thread(parent_box : pointer; x, y : scaled);
  var p: pointer;
  begin p  $\leftarrow$  get_node(pdf_thread_node_size); info(p)  $\leftarrow$  max_halfword; { this is not a whatsit node }
  link(p)  $\leftarrow$  null; { this node will be destroyed separately }
  pdf_width(p)  $\leftarrow$  pdf_thread_wd; pdf_height(p)  $\leftarrow$  pdf_thread_ht; pdf_depth(p)  $\leftarrow$  pdf_thread_dp;
  pdf_thread_attr(p)  $\leftarrow$  null; pdf_thread_id(p)  $\leftarrow$  pdf_last_thread_id;
  if pdf_last_thread_named_id then
    begin add_token_ref(pdf_thread_id(p)); pdf_thread_named_id(p)  $\leftarrow$  1;
    end
  else pdf_thread_named_id(p)  $\leftarrow$  0;
  set_rect_dimens(p, parent_box, x, y, pdf_width(p), pdf_height(p), pdf_depth(p), pdf_thread_margin);
  append_bead(p); last_thread  $\leftarrow$  p;
  end;

procedure end_thread;
  begin if pdf_thread_level  $\neq$  cur_s then pdf_error("ext4",
    "\pdfendthread_ended_up_in_different_nesting_level_than_\pdfstartthread");
  if is_running(pdf_thread_dp)  $\wedge$  (last_thread  $\neq$  null) then
    pdf_bottom(last_thread)  $\leftarrow$  cur_v + pdf_thread_margin;
  if pdf_last_thread_named_id then delete_token_ref(pdf_last_thread_id);
  last_thread  $\leftarrow$  null;
  end;

function open_subentries(p : pointer): integer;
  var k, c: integer; l, r: integer;

```



```

begin  $k \leftarrow 0$ ;
if  $\text{obj\_outline\_first}(p) \neq 0$  then
  begin  $l \leftarrow \text{obj\_outline\_first}(p)$ ;
  repeat  $\text{incr}(k)$ ;  $c \leftarrow \text{open\_subentries}(l)$ ;
    if  $\text{obj\_outline\_count}(l) > 0$  then  $k \leftarrow k + c$ ;
     $\text{obj\_outline\_parent}(l) \leftarrow p$ ;  $r \leftarrow \text{obj\_outline\_next}(l)$ ;
    if  $r = 0$  then  $\text{obj\_outline\_last}(p) \leftarrow l$ ;
     $l \leftarrow r$ ;
  until  $l = 0$ ;
  end;
if  $\text{obj\_outline\_count}(p) > 0$  then  $\text{obj\_outline\_count}(p) \leftarrow k$ 
else  $\text{obj\_outline\_count}(p) \leftarrow -k$ ;
 $\text{open\_subentries} \leftarrow k$ ;
end;
procedure  $\text{do\_dest}(p, \text{parent\_box} : \text{pointer}; x, y : \text{scaled})$ ;
  var  $k$ : integer;
  begin if  $\neg \text{is\_shipping\_page}$  then  $\text{pdf\_error}(\text{"ext4"}, \text{"destinations\_cannot\_be\_inside\_an\_XForm"})$ ;
  if  $\text{doing\_leaders}$  then return;
   $k \leftarrow \text{get\_obj}(\text{obj\_type\_dest}, \text{pdf\_dest\_id}(p), \text{pdf\_dest\_named\_id}(p))$ ;
  if  $\text{obj\_dest\_ptr}(k) \neq \text{null}$  then
    begin  $\text{warn\_dest\_dup}(\text{pdf\_dest\_id}(p), \text{pdf\_dest\_named\_id}(p), \text{"ext4"},$ 
       $\text{"has\_been\_already\_used,\_duplicate\_ignored"})$ ; return;
    end;
   $\text{obj\_dest\_ptr}(k) \leftarrow p$ ;  $\text{pdf\_append\_list}(k)(\text{pdf\_dest\_list})$ ;
  case  $\text{pdf\_dest\_type}(p)$  of
     $\text{pdf\_dest\_xyz}$ : if  $\text{matrixused}$  then
       $\text{set\_rect\_dimens}(p, \text{parent\_box}, x, y, \text{pdf\_width}(p), \text{pdf\_height}(p), \text{pdf\_depth}(p), \text{pdf\_dest\_margin})$ 
    else begin  $\text{pdf\_left}(p) \leftarrow \text{cur\_h}$ ;  $\text{pdf\_top}(p) \leftarrow \text{cur\_v}$ ;
    end;
     $\text{pdf\_dest\_fith}, \text{pdf\_dest\_fitbh}$ : if  $\text{matrixused}$  then
       $\text{set\_rect\_dimens}(p, \text{parent\_box}, x, y, \text{pdf\_width}(p), \text{pdf\_height}(p), \text{pdf\_depth}(p), \text{pdf\_dest\_margin})$ 
    else  $\text{pdf\_top}(p) \leftarrow \text{cur\_v}$ ;
     $\text{pdf\_dest\_fitv}, \text{pdf\_dest\_fitbv}$ : if  $\text{matrixused}$  then
       $\text{set\_rect\_dimens}(p, \text{parent\_box}, x, y, \text{pdf\_width}(p), \text{pdf\_height}(p), \text{pdf\_depth}(p), \text{pdf\_dest\_margin})$ 
    else  $\text{pdf\_left}(p) \leftarrow \text{cur\_h}$ ;
     $\text{pdf\_dest\_fit}, \text{pdf\_dest\_fitb}$ :  $\text{do\_nothing}$ ;
     $\text{pdf\_dest\_fitr}$ :  $\text{set\_rect\_dimens}(p, \text{parent\_box}, x, y, \text{pdf\_width}(p), \text{pdf\_height}(p), \text{pdf\_depth}(p), \text{pdf\_dest\_margin})$ ;
  endcases;
  end;
procedure  $\text{out\_form}(p : \text{pointer})$ ;
  begin  $\text{pdf\_end\_text}$ ;  $\text{pdf\_print\_ln}(\text{"q"})$ ;
  if  $\text{pdf\_lookup\_list}(\text{pdf\_xform\_list}, \text{pdf\_xform\_objnum}(p)) = \text{null}$  then
     $\text{pdf\_append\_list}(\text{pdf\_xform\_objnum}(p))(\text{pdf\_xform\_list})$ ;
     $\text{cur\_v} \leftarrow \text{cur\_v} + \text{obj\_xform\_depth}(\text{pdf\_xform\_objnum}(p))$ ;  $\text{pdf\_print}(\text{"1\_0\_0\_1"})$ ;
     $\text{pdf\_print\_bp}(\text{pdf\_x}(\text{cur\_h}))$ ;  $\text{pdf\_out}(\text{" "})$ ;  $\text{pdf\_print\_bp}(\text{pdf\_y}(\text{cur\_v}))$ ;  $\text{pdf\_print\_ln}(\text{"\_cm"})$ ;
     $\text{pdf\_print}(\text{" /Fm"})$ ;  $\text{pdf\_print\_int}(\text{obj\_info}(\text{pdf\_xform\_objnum}(p)))$ ;  $\text{pdf\_print\_resname\_prefix}$ ;
     $\text{pdf\_print\_ln}(\text{"\_Do"})$ ;  $\text{pdf\_print\_ln}(\text{"Q"})$ ;
  end;
procedure  $\text{out\_image}(p : \text{pointer})$ ;
  var  $\text{image}, \text{groupref}$ : integer;  $\text{img\_w}, \text{img\_h}$ : integer;
  begin  $\text{image} \leftarrow \text{obj\_ximage\_data}(\text{pdf\_ximage\_objnum}(p))$ ;
  if  $(\text{image\_rotate}(\text{image}) = 90) \vee (\text{image\_rotate}(\text{image}) = 270)$  then

```

```

    begin img_h ← image_width(image); img_w ← image_height(image);
    end
else begin img_w ← image_width(image); img_h ← image_height(image);
    end;
pdf_end_text; pdf_print_ln("q");
if pdf_lookup_list(pdf_ximage_list, pdf_ximage_objnum(p)) = null then
    pdf_append_list(pdf_ximage_objnum(p))(pdf_ximage_list);
if ¬is_pdf_image(image) then
    begin if is_png_image(image) then
        begin groupref ← get_image_group_ref(image);
        if (groupref > 0) ∧ (pdf_page_group_val = 0) then pdf_page_group_val ← groupref;
        end;
pdf_print_real(ext_xn_over_d(pdf_width(p), ten_pow[6], one_hundred_bp), 4); pdf_print("000");
pdf_print_real(ext_xn_over_d(pdf_height(p) + pdf_depth(p), ten_pow[6], one_hundred_bp), 4);
pdf_out(" "); pdf_print_bp(pdf_x(cur_h)); pdf_out(" "); pdf_print_bp(pdf_y(cur_v));
    end
else begin { for pdf images we generate the page group object number here }
    groupref ← get_image_group_ref(image); { 0: no group, -1: to be generated; 0: already written }
    if (groupref ≠ 0) ∧ (pdf_page_group_val = 0) then
        begin if groupref = -1 then
            begin pdf_page_group_val ← pdf_new_objnum; set_image_group_ref(image, pdf_page_group_val);
            end
        else { groupref 0 }
            pdf_page_group_val ← groupref;
        end;
pdf_print_real(ext_xn_over_d(pdf_width(p), ten_pow[6], img_w), 6); pdf_print("000");
pdf_print_real(ext_xn_over_d(pdf_height(p) + pdf_depth(p), ten_pow[6], img_h), 6); pdf_out(" ");
pdf_print_bp(pdf_x(cur_h) - ext_xn_over_d(pdf_width(p), pdf_orig_x(image), img_w)); pdf_out(" ");
pdf_print_bp(pdf_y(cur_v) - ext_xn_over_d(pdf_height(p) + pdf_depth(p), pdf_orig_y(image), img_h));
    end;
pdf_print_ln("cm"); pdf_print("/Im"); pdf_print_int(obj_info(pdf_ximage_objnum(p)));
pdf_print_resname_prefix; pdf_print_ln("Do"); pdf_print_ln("Q");
end;
function gap_amount(p : pointer; cur_pos : scaled): scaled;
    { find the gap between the position of the current snap node p and the nearest point on the grid }
var snap_unit, stretch_amount, shrink_amount: scaled; last_pos, next_pos, g, g2: scaled;
begin snap_unit ← width(snap_glue_ptr(p));
if stretch_order(snap_glue_ptr(p)) > normal then stretch_amount ← max_dimen
else stretch_amount ← stretch(snap_glue_ptr(p));
if shrink_order(snap_glue_ptr(p)) > normal then shrink_amount ← max_dimen
else shrink_amount ← shrink(snap_glue_ptr(p));
if subtype(p) = pdf_snap_node then
    last_pos ← pdf_snap_refpos + snap_unit * ((cur_pos - pdf_snap_refpos) div snap_unit)
else pdf_error("snapping", "invalid parameter value for gap_amount");
next_pos ← last_pos + snap_unit; @{print_ln("snap_refpos="); print_scaled(pdf_snap_refpos);
print_ln("snap_glue="); print_spec(snap_glue_ptr(p), 0); print_ln("gap_amount=");
print_scaled(snap_unit); print_ln("stretch_amount="); print_scaled(stretch_amount);
print_ln("shrink_amount="); print_scaled(shrink_amount); print_ln("last_point=");
print_scaled(last_pos); print_ln("cur_point="); print_scaled(cur_pos); print_ln("next_point=");
print_scaled(next_pos); @}g ← max_dimen; g2 ← max_dimen; gap_amount ← 0;
if cur_pos - last_pos < shrink_amount then g ← cur_pos - last_pos;
if (next_pos - cur_pos < stretch_amount) then g2 ← next_pos - cur_pos;

```

```

if ( $g = \text{max\_dimen}$ )  $\wedge$  ( $g2 = \text{max\_dimen}$ ) then return; { unable to snap }
if  $g2 \leq g$  then  $\text{gap\_amount} \leftarrow g2$  { skip forward }
else  $\text{gap\_amount} \leftarrow -g$ ; { skip backward }
end;
function  $\text{get\_vpos}(p, q, b : \text{pointer})$ :  $\text{pointer}$ ;
    { find the vertical position of node  $q$  in the output PDF page; this functions is called when the
      current node is  $p$  and current position is  $\text{cur\_v}$  (global variable);  $b$  is the parent box; }
var  $\text{tmp\_v}$ :  $\text{scaled}$ ;  $\text{g\_order}$ :  $\text{glue\_ord}$ ; { applicable order of infinity for glue }
     $\text{g\_sign}$ :  $\text{normal} \dots \text{shrinking}$ ; { selects type of glue }
     $\text{glue\_temp}$ :  $\text{real}$ ; { glue value before rounding }
     $\text{cur\_glue}$ :  $\text{real}$ ; { glue seen so far }
     $\text{cur\_g}$ :  $\text{scaled}$ ; { rounded equivalent of  $\text{cur\_glue}$  times the glue ratio }
     $\text{this\_box}$ :  $\text{pointer}$ ; { pointer to containing box }
begin  $\text{tmp\_v} \leftarrow \text{cur\_v}$ ;  $\text{this\_box} \leftarrow b$ ;  $\text{cur\_g} \leftarrow 0$ ;  $\text{cur\_glue} \leftarrow \text{float\_constant}(0)$ ;
 $\text{g\_order} \leftarrow \text{glue\_order}(\text{this\_box})$ ;  $\text{g\_sign} \leftarrow \text{glue\_sign}(\text{this\_box})$ ;
while ( $p \neq q$ )  $\wedge$  ( $p \neq \text{null}$ ) do
    begin if  $\text{is\_char\_node}(p)$  then  $\text{confusion}(\text{"get\_vpos"})$ 
    else begin case  $\text{type}(p)$  of
         $\text{hlist\_node}, \text{vlist\_node}, \text{rule\_node}$ :  $\text{tmp\_v} \leftarrow \text{tmp\_v} + \text{height}(p) + \text{depth}(p)$ ;
         $\text{whatsit\_node}$ : if ( $\text{subtype}(p) = \text{pdf\_refxform\_node}$ )  $\vee$  ( $\text{subtype}(p) = \text{pdf\_refximage\_node}$ ) then
             $\text{tmp\_v} \leftarrow \text{tmp\_v} + \text{pdf\_height}(p) + \text{pdf\_depth}(p)$ ;
         $\text{glue\_node}$ : begin { Move down without outputting leaders 1635 };
             $\text{tmp\_v} \leftarrow \text{tmp\_v} + \text{rule\_ht}$ ;
        end;
         $\text{kern\_node}$ :  $\text{tmp\_v} \leftarrow \text{tmp\_v} + \text{width}(p)$ ;
        othercases  $\text{do\_nothing}$ ;
    endcases;
    end;
     $p \leftarrow \text{link}(p)$ ;
end;
 $\text{get\_vpos} \leftarrow \text{tmp\_v}$ ;
end;
procedure  $\text{do\_snappy\_comp}(p, b : \text{pointer})$ ; { do snapping compensation in vertical direction; search for
    the next snap node and do the compensation if found }
var  $q$ :  $\text{pointer}$ ;  $\text{tmp\_v}, g, g2$ :  $\text{scaled}$ ;
begin if  $\neg(\text{is\_char\_node}(p) \wedge (\text{type}(p) = \text{whatsit\_node}) \wedge (\text{subtype}(p) = \text{pdf\_snappy\_comp\_node}))$  then
     $\text{pdf\_error}(\text{"snapping"}, \text{"invalid\_parameter\_value\_for\_do\_snappy\_comp"})$ ;
 $q \leftarrow p$ ;
while ( $q \neq \text{null}$ ) do
    begin if  $\neg\text{is\_char\_node}(q) \wedge (\text{type}(q) = \text{whatsit\_node}) \wedge (\text{subtype}(q) = \text{pdf\_snappy\_node})$  then
        begin  $\text{tmp\_v} \leftarrow \text{get\_vpos}(p, q, b)$ ; { get the position of  $q$  }
         $g \leftarrow \text{gap\_amount}(q, \text{tmp\_v})$ ; { get the gap to the grid }
         $g2 \leftarrow \text{round\_xn\_over\_d}(g, \text{snappy\_comp\_ratio}(p), 1000)$ ; { adjustment for  $p$  }
        @ $\{\text{print\_nl}(\text{"do\_snappy\_comp: \_tmp\_v\_="})$ ;  $\text{print\_scaled}(\text{tmp\_v})$ ;
         $\text{print\_nl}(\text{"do\_snappy\_comp: \_cur\_v\_="})$ ;  $\text{print\_scaled}(\text{cur\_v})$ ;  $\text{print\_nl}(\text{"do\_snappy\_comp: \_g\_="})$ ;
         $\text{print\_scaled}(g)$ ;  $\text{print\_nl}(\text{"do\_snappy\_comp: \_g2\_="})$ ;  $\text{print\_scaled}(g2)$ ; @ $\}\text{cur\_v} \leftarrow \text{cur\_v} + g2$ ;
         $\text{final\_skip}(q) \leftarrow g - g2$ ; { adjustment for  $q$  }
        if  $\text{final\_skip}(q) = 0$  then  $\text{final\_skip}(q) \leftarrow 1$ ;
            { use 1sp as the magic value to record that  $\text{final\_skip}$  has been set here }
        return;
    end;
     $q \leftarrow \text{link}(q)$ ;

```

```

    end;
  end;
procedure do_snap(p : pointer);
begin incr(count_do_snap); @{print_nl("do_snap: count="); print_int(count_do_snap);
    print_nl("do_snap: cur_v="); print_scaled(cur_v); print_nl("do_snap: final_skip=");
    print_scaled(final_skip(p)); @}
    if final_skip(p)  $\neq$  0 then cur_v  $\leftarrow$  cur_v + final_skip(p)
    else cur_v  $\leftarrow$  cur_v + gap_amount(p, cur_v);
    @{print_nl("do_snap: cur_v after snap="); print_scaled(cur_v); @}
end;

```

1635. \langle Move down without outputting leaders [1635](#) $\rangle \equiv$

```

begin g  $\leftarrow$  glue_ptr(p); rule_ht  $\leftarrow$  width(g) - cur_g;
if g_sign  $\neq$  normal then
  begin if g_sign = stretching then
    begin if stretch_order(g) = g_order then
      begin cur_glue  $\leftarrow$  cur_glue + stretch(g); vet_glue(float(glue_set(this_box)) * cur_glue);
      cur_g  $\leftarrow$  round(glue_temp);
      end;
    end
  else if shrink_order(g) = g_order then
    begin cur_glue  $\leftarrow$  cur_glue - shrink(g); vet_glue(float(glue_set(this_box)) * cur_glue);
    cur_g  $\leftarrow$  round(glue_temp);
    end;
  end;
  rule_ht  $\leftarrow$  rule_ht + cur_g;
end

```

This code is used in section [1634](#).

1636. \langle Output the whatsit node p in *pdf_vlist_out* 1636 $\rangle \equiv$

```

case subtype( $p$ ) of
  pdf_literal_node: pdf_out.literal( $p$ );
  pdf_colorstack_node: pdf_out.colorstack( $p$ );
  pdf_setmatrix_node: pdf_out.setmatrix( $p$ );
  pdf_save_node: pdf_out.save( $p$ );
  pdf_restore_node: pdf_out.restore( $p$ );
  pdf_refobj_node: pdf_append_list(pdf_obj_objnum( $p$ ))(pdf_obj_list);
  pdf_refxform_node:  $\langle$  Output a Form node in a vlist 1641  $\rangle$ ;
  pdf_refximage_node:  $\langle$  Output a Image node in a vlist 1640  $\rangle$ ;
  pdf_annot_node: do_annot( $p$ , this_box, left_edge, top_edge + height(this_box));
  pdf_start_link_node: pdf_error("ext4", "\pdfstartlink ended up in vlist");
  pdf_end_link_node: pdf_error("ext4", "\pdfendlink ended up in vlist");
  pdf_dest_node: do_dest( $p$ , this_box, left_edge, top_edge + height(this_box));
  pdf_thread_node, pdf_start_thread_node: do_thread( $p$ , this_box, left_edge, top_edge + height(this_box));
  pdf_end_thread_node: end_thread;
  pdf_save_pos_node:  $\langle$  Save current position to pdf_last_x_pos, pdf_last_y_pos 1638  $\rangle$ ;
  special_node: pdf_special( $p$ );
  pdf_snap_ref_point_node:  $\langle$  Save current position to pdf_snapx_refpos, pdf_snapy_refpos 1639  $\rangle$ ;
  pdf_snapy_comp_node: do_snapy_comp( $p$ , this_box);
  pdf_snapy_node: do_snapy( $p$ );
  pdf_interword_space_on_node: gen_faked_interword_space  $\leftarrow$  true;
  pdf_interword_space_off_node: gen_faked_interword_space  $\leftarrow$  false;
  pdf_fake_space_node: pdf_insert_fake_space;
  pdf_running_link_off_node: gen_running_link  $\leftarrow$  false;
  pdf_running_link_on_node: gen_running_link  $\leftarrow$  true;
othercases out_what( $p$ );
endcases

```

This code is used in section 741.

1637. \langle Global variables 13 $\rangle + \equiv$

is_shipping_page: boolean; { set to *shipping_page* when *pdf_ship_out* starts }

1638. \langle Save current position to *pdf_last_x_pos*, *pdf_last_y_pos* 1638 $\rangle \equiv$

```

begin pdf_last_x_pos  $\leftarrow$  cur_h;
if is_shipping_page then pdf_last_y_pos  $\leftarrow$  cur_page_height - cur_v
else pdf_last_y_pos  $\leftarrow$  pdf_xform_height + pdf_xform_depth - cur_v;
end

```

This code is used in sections 1636 and 1642.

1639. \langle Save current position to *pdf_snapx_refpos*, *pdf_snapy_refpos* 1639 $\rangle \equiv$

```

begin pdf_snapx_refpos  $\leftarrow$  cur_h; pdf_snapy_refpos  $\leftarrow$  cur_v;
end

```

This code is used in sections 1636 and 1642.

1640. \langle Output a Image node in a vlist 1640 $\rangle \equiv$

```

begin cur_v  $\leftarrow$  cur_v + pdf_height( $p$ ) + pdf_depth( $p$ ); save_v  $\leftarrow$  cur_v; cur_h  $\leftarrow$  left_edge; out_image( $p$ );
  cur_v  $\leftarrow$  save_v; cur_h  $\leftarrow$  left_edge;
end

```

This code is used in section 1636.

1641. \langle Output a Form node in a vlist 1641 $\rangle \equiv$

```
begin cur_v  $\leftarrow$  cur_v + pdf_height(p); save_v  $\leftarrow$  cur_v; cur_h  $\leftarrow$  left_edge; out_form(p);
cur_v  $\leftarrow$  save_v + pdf_depth(p); cur_h  $\leftarrow$  left_edge;
end
```

This code is used in section 1636.

1642. \langle Output the whatsit node p in pdf_hlist_out 1642 $\rangle \equiv$

```
case subtype(p) of
pdf_literal_node: pdf_out_literal(p);
pdf_colorstack_node: pdf_out_colorstack(p);
pdf_setmatrix_node: pdf_out_setmatrix(p);
pdf_save_node: pdf_out_save(p);
pdf_restore_node: pdf_out_restore(p);
pdf_refobj_node: pdf_append_list(pdf_obj_objnum(p))(pdf_obj_list);
pdf_refxform_node:  $\langle$  Output a Form node in a hlist 1644  $\rangle$ ;
pdf_refximage_node:  $\langle$  Output a Image node in a hlist 1643  $\rangle$ ;
pdf_annot_node: do_annot(p, this_box, left_edge, base_line);
pdf_start_link_node: do_link(p, this_box, left_edge, base_line);
pdf_end_link_node: end_link;
pdf_dest_node: do_dest(p, this_box, left_edge, base_line);
pdf_thread_node: do_thread(p, this_box, left_edge, base_line);
pdf_start_thread_node: pdf_error("ext4", "\pdfstartthread_ended_up_in_hlist");
pdf_end_thread_node: pdf_error("ext4", "\pdfendthread_ended_up_in_hlist");
pdf_save_pos_node:  $\langle$  Save current position to pdf_last_x_pos, pdf_last_y_pos 1638  $\rangle$ ;
special_node: pdf_special(p);
pdf_snap_ref_point_node:  $\langle$  Save current position to pdf_snapx_refpos, pdf_snapy_refpos 1639  $\rangle$ ;
pdf_snap_comp_node, pdf_snap_node: do_nothing; {snap nodes do nothing in hlist}
pdf_interword_space_on_node: gen_faked_interword_space  $\leftarrow$  true;
pdf_interword_space_off_node: gen_faked_interword_space  $\leftarrow$  false;
pdf_fake_space_node: pdf_insert_fake_space;
pdf_running_link_off_node: gen_running_link  $\leftarrow$  false;
pdf_running_link_on_node: gen_running_link  $\leftarrow$  true;
othercases out_what(p);
endcases
```

This code is used in section 732.

1643. \langle Output a Image node in a hlist 1643 $\rangle \equiv$

```
begin cur_v  $\leftarrow$  base_line + pdf_depth(p); edge  $\leftarrow$  cur_h; out_image(p); cur_h  $\leftarrow$  edge + pdf_width(p);
cur_v  $\leftarrow$  base_line;
end
```

This code is used in section 1642.

1644. \langle Output a Form node in a hlist 1644 $\rangle \equiv$

```
begin cur_v  $\leftarrow$  base_line; edge  $\leftarrow$  cur_h; out_form(p); cur_h  $\leftarrow$  edge + pdf_width(p); cur_v  $\leftarrow$  base_line;
end
```

This code is used in section 1642.

1645. The extended features of ε -TeX. The program has two modes of operation: (1) In TeX compatibility mode it fully deserves the name TeX and there are neither extended features nor additional primitive commands. There are, however, a few modifications that would be legitimate in any implementation of TeX such as, e.g., preventing inadequate results of the glue to DVI unit conversion during *ship.out*. (2) In extended mode there are additional primitive commands and the extended features of ε -TeX are available.

The distinction between these two modes of operation initially takes place when a ‘virgin’ eINITEX starts without reading a format file. Later on the values of all ε -TeX state variables are inherited when eVIRTEX (or eINITEX) reads a format file.

The code below is designed to work for cases where ‘init ... tini’ is a run-time switch.

```

< Enable  $\varepsilon$ -TeX, if requested 1645 >  $\equiv$ 
  init if (buffer[loc] = "*" )  $\wedge$  (format_ident = "\_ (INITEX) ") then
    begin no_new_control_sequence  $\leftarrow$  false; < Generate all  $\varepsilon$ -TeX primitives 1646 >
      incr(loc); eTeX_mode  $\leftarrow$  1; { enter extended mode }
      < Initialize variables for  $\varepsilon$ -TeX extended mode 1810 >
    end;
  tini
  if  $\neg$ no_new_control_sequence then { just entered extended mode ? }
    no_new_control_sequence  $\leftarrow$  true else

```

This code is used in section 1515.

1646. The ε -TeX features available in extended mode are grouped into two categories: (1) Some of them are permanently enabled and have no semantic effect as long as none of the additional primitives are executed. (2) The remaining ε -TeX features are optional and can be individually enabled and disabled. For each optional feature there is an ε -TeX state variable named \...state; the feature is enabled, resp. disabled by assigning a positive, resp. non-positive value to that integer.

```

  define eTeX_state_base = int_base + eTeX_state_code
  define eTeX_state(#)  $\equiv$  eqtb[eTeX_state_base + #].int { an  $\varepsilon$ -TeX state variable }
  define eTeX_version_code = eTeX_int { code for \eTeXversion }
< Generate all  $\varepsilon$ -TeX primitives 1646 >  $\equiv$ 
  primitive("lastnodetype", last_item, last_node_type_code);
  primitive("eTeXversion", last_item, eTeX_version_code);
  primitive("eTeXrevision", convert, eTeX_revision_code);

```

See also sections 1654, 1660, 1663, 1666, 1669, 1672, 1681, 1683, 1686, 1689, 1694, 1698, 1744, 1756, 1759, 1767, 1775, 1798, 1802, 1806, 1858, and 1861.

This code is used in section 1645.

```

1647. < Cases of last_item for print_cmd_chr 1647 >  $\equiv$ 
last_node_type_code: print_esc("lastnodetype");
eTeX_version_code: print_esc("eTeXversion");

```

See also sections 1661, 1664, 1667, 1670, 1776, 1799, and 1803.

This code is used in section 443.

```

1648. < Cases for fetching an integer value 1648 >  $\equiv$ 
eTeX_version_code: cur_val  $\leftarrow$  eTeX_version;

```

See also sections 1662, 1665, and 1800.

This code is used in section 450.

```

1649. define eTeX_ex  $\equiv$  (eTeX_mode = 1) { is this extended mode? }
< Global variables 13 > + $\equiv$ 
eTeX_mode: 0 .. 1; { identifies compatibility and extended mode }

```

1650. \langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$
 $eTeX_mode \leftarrow 0$; { initially we are in compatibility mode }
 \langle Initialize variables for ε -TEX compatibility mode 1809 \rangle

1651. \langle Dump the ε -TEX state 1651 $\rangle \equiv$
 $dump_int(eTeX_mode)$;
for $j \leftarrow 0$ **to** $eTeX_states - 1$ **do** $eTeX_state(j) \leftarrow 0$; { disable all enhancements }

See also section 1755.

This code is used in section 1483.

1652. \langle Undump the ε -TEX state 1652 $\rangle \equiv$
 $undump(0)(1)(eTeX_mode)$;
if $eTeX_ex$ **then**
 begin \langle Initialize variables for ε -TEX extended mode 1810 \rangle
 end
else begin \langle Initialize variables for ε -TEX compatibility mode 1809 \rangle
 end;

This code is used in section 1484.

1653. The $eTeX_enabled$ function simply returns its first argument as result. This argument is *true* if an optional ε -TEX feature is currently enabled; otherwise, if the argument is *false*, the function gives an error message.

\langle Declare ε -TEX procedures for use by *main_control* 1653 $\rangle \equiv$
function $eTeX_enabled(b : \text{boolean}; j : \text{quarterword}; k : \text{halfword}) : \text{boolean}$;
 begin if $\neg b$ **then**
 begin $print_err(\text{"Improper_"}); print_cmd_chr(j, k)$;
 $help1(\text{"Sorry, _this_optional_e-TeX_feature_has_been_disabled."})$; *error*;
 end;
 $eTeX_enabled \leftarrow b$;
 end;

See also sections 1676 and 1692.

This code is used in section 989.

1654. First we implement the additional ε -TEX parameters in the table of equivalents.

\langle Generate all ε -TEX primitives 1646 $\rangle + \equiv$
 $primitive(\text{"everyeof"}, assign_toks, every_eof_loc)$;
 $primitive(\text{"tracingassigns"}, assign_int, int_base + tracing_assigns_code)$;
 $primitive(\text{"tracinggroups"}, assign_int, int_base + tracing_groups_code)$;
 $primitive(\text{"tracingifs"}, assign_int, int_base + tracing_ifs_code)$;
 $primitive(\text{"tracingscantokens"}, assign_int, int_base + tracing_scan_tokens_code)$;
 $primitive(\text{"tracingnesting"}, assign_int, int_base + tracing_nesting_code)$;
 $primitive(\text{"predisplaydirection"}, assign_int, int_base + pre_display_direction_code)$;
 $primitive(\text{"lastlinefit"}, assign_int, int_base + last_line_fit_code)$;
 $primitive(\text{"savingvdiscards"}, assign_int, int_base + saving_vdiscards_code)$;
 $primitive(\text{"savinghyphcodes"}, assign_int, int_base + saving_hyph_codes_code)$;

1655. **define** $every_eof \equiv equiv(every_eof_loc)$

\langle Cases of $assign_toks$ for $print_cmd_chr$ 1655 $\rangle \equiv$
 $every_eof_loc : print_esc(\text{"everyeof"})$;

This code is used in section 249.

1656. \langle Cases for *print_param* 1656 $\rangle \equiv$
tracing_assigns_code: *print_esc*("tracingassigns");
tracing_groups_code: *print_esc*("tracinggroups");
tracing_ifs_code: *print_esc*("tracingifs");
tracing_scan_tokens_code: *print_esc*("tracingscantokens");
tracing_nesting_code: *print_esc*("tracingnesting");
pre_display_direction_code: *print_esc*("predisplaydirection");
last_line_fit_code: *print_esc*("lastlinefit");
saving_vdiscards_code: *print_esc*("savingvdiscards");
saving_hyph_codes_code: *print_esc*("savinghyphcodes");

See also section 1697.

This code is used in section 255.

1657. In order to handle `\everyeof` we need an array *eof_seen* of boolean variables.

\langle Global variables 13 $\rangle + \equiv$
eof_seen: **array** [1 .. *max_in_open*] **of** *boolean*; { has eof been seen? }

1658. The *print_group* procedure prints the current level of grouping and the name corresponding to *cur_group*.

(Declare ε -TEX procedures for tracing and input 306) \equiv

```
procedure print_group(e : boolean);
  label exit;
  begin case cur_group of
    bottom_level: begin print("bottom_level"); return;
    end;
    simple_group, semi_simple_group: begin if cur_group = semi_simple_group then print("semi_");
      print("simple");
    end;
    hbox_group, adjusted_hbox_group: begin if cur_group = adjusted_hbox_group then print("adjusted_");
      print("hbox");
    end;
    vbox_group: print("vbox");
    vtop_group: print("vtop");
    align_group, no_align_group: begin if cur_group = no_align_group then print("no_");
      print("align");
    end;
    output_group: print("output");
    disc_group: print("disc");
    insert_group: print("insert");
    vcenter_group: print("vcenter");
    math_group, math_choice_group, math_shift_group, math_left_group: begin print("math");
      if cur_group = math_choice_group then print("_choice")
      else if cur_group = math_shift_group then print("_shift")
      else if cur_group = math_left_group then print("_left");
    end;
  end; { there are no other cases }
  print("_group_(level_"); print_int(qo(cur_level)); print_char("");
  if saved(-1)  $\neq$  0 then
    begin if e then print("_entered_at_line_")
    else print("_at_line_");
    print_int(saved(-1));
  end;
exit: end;
```

1659. The *group_trace* procedure is called when a new level of grouping begins (*e* = *false*) or ends (*e* = *true*) with *saved*(-1) containing the line number.

(Declare ε -TEX procedures for tracing and input 306) \equiv

```
stat procedure group_trace(e : boolean);
begin begin_diagnostic; print_char("{");
if e then print("leaving_")
else print("entering_");
print_group(e); print_char("}"); end_diagnostic(false);
end;
tats
```

1660. The `\currentgrouplevel` and `\currentgrouptype` commands return the current level of grouping and the type of the current group respectively.

```

define current_group_level_code = eTeX_int + 1 { code for \currentgrouplevel }
define current_group_type_code = eTeX_int + 2 { code for \currentgrouptype }
⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩ +≡
  primitive("currentgrouplevel", last_item, current_group_level_code);
  primitive("currentgrouptype", last_item, current_group_type_code);

```

1661. ⟨Cases of *last_item* for *print_cmd_chr* 1647⟩ +≡
current_group_level_code: *print_esc*("currentgrouplevel");
current_group_type_code: *print_esc*("currentgrouptype");

1662. ⟨Cases for fetching an integer value 1648⟩ +≡
current_group_level_code: *cur_val* \leftarrow *cur_level* − *level_one*;
current_group_type_code: *cur_val* \leftarrow *cur_group*;

1663. The `\currentiflevel`, `\currentiftype`, and `\currentifbranch` commands return the current level of conditionals and the type and branch of the current conditional.

```

define current_if_level_code = eTeX_int + 3 { code for \currentiflevel }
define current_if_type_code = eTeX_int + 4 { code for \currentiftype }
define current_if_branch_code = eTeX_int + 5 { code for \currentifbranch }
⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩ +≡
  primitive("currentiflevel", last_item, current_if_level_code);
  primitive("currentiftype", last_item, current_if_type_code);
  primitive("currentifbranch", last_item, current_if_branch_code);

```

1664. ⟨Cases of *last_item* for *print_cmd_chr* 1647⟩ +≡
current_if_level_code: *print_esc*("currentiflevel");
current_if_type_code: *print_esc*("currentiftype");
current_if_branch_code: *print_esc*("currentifbranch");

1665. ⟨Cases for fetching an integer value 1648⟩ +≡
current_if_level_code: **begin** *q* \leftarrow *cond_ptr*; *cur_val* \leftarrow 0;
 while *q* \neq *null* **do**
 begin *incr*(*cur_val*); *q* \leftarrow *link*(*q*);
 end;
 end;
current_if_type_code: **if** *cond_ptr* = *null* **then** *cur_val* \leftarrow 0
 else if *cur_if* < *unless_code* **then** *cur_val* \leftarrow *cur_if* + 1
 else *cur_val* \leftarrow −(*cur_if* − *unless_code* + 1);
current_if_branch_code: **if** (*if_limit* = *or_code*) \vee (*if_limit* = *else_code*) **then** *cur_val* \leftarrow 1
 else if *if_limit* = *fi_code* **then** *cur_val* \leftarrow −1
 else *cur_val* \leftarrow 0;

1666. The `\fontcharwd`, `\fontcharht`, `\fontchardp`, and `\fontcharic` commands return information about a character in a font.

```

define font_char_wd_code = eTeX_dim { code for \fontcharwd }
define font_char_ht_code = eTeX_dim + 1 { code for \fontcharht }
define font_char_dp_code = eTeX_dim + 2 { code for \fontchardp }
define font_char_ic_code = eTeX_dim + 3 { code for \fontcharic }

⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩ +=
  primitive("fontcharwd", last_item, font_char_wd_code);
  primitive("fontcharht", last_item, font_char_ht_code);
  primitive("fontchardp", last_item, font_char_dp_code);
  primitive("fontcharic", last_item, font_char_ic_code);

```

1667. ⟨Cases of *last_item* for *print_cmd_chr* 1647⟩ +=
font_char_wd_code: *print_esc*("fontcharwd");
font_char_ht_code: *print_esc*("fontcharht");
font_char_dp_code: *print_esc*("fontchardp");
font_char_ic_code: *print_esc*("fontcharic");

1668. ⟨Cases for fetching a dimension value 1668⟩ ≡
font_char_wd_code, *font_char_ht_code*, *font_char_dp_code*, *font_char_ic_code*: **begin** *scan_font_ident*;
 q ← *cur_val*; *scan_char_num*;
 if (*font_bc*[*q*] ≤ *cur_val*) ∧ (*font_ec*[*q*] ≥ *cur_val*) **then**
 begin *i* ← *char_info*(*q*)(*qi*(*cur_val*));
 case *m* **of**
 font_char_wd_code: *cur_val* ← *char_width*(*q*)(*i*);
 font_char_ht_code: *cur_val* ← *char_height*(*q*)(*height_depth*(*i*));
 font_char_dp_code: *cur_val* ← *char_depth*(*q*)(*height_depth*(*i*));
 font_char_ic_code: *cur_val* ← *char_italic*(*q*)(*i*);
 end; { there are no other cases }
 end
 else *cur_val* ← 0;
 end;

See also sections 1671 and 1801.

This code is used in section 450.

1669. The `\parshapedimen`, `\parshapeindent`, and `\parshapelength` commands return the indent and length parameters of the current `\parshape` specification.

```

define par_shape_length_code = eTeX_dim + 4 { code for \parshapelength }
define par_shape_indent_code = eTeX_dim + 5 { code for \parshapeindent }
define par_shape_dimen_code = eTeX_dim + 6 { code for \parshapedimen }

⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩ +=
  primitive("parshapelength", last_item, par_shape_length_code);
  primitive("parshapeindent", last_item, par_shape_indent_code);
  primitive("parshapedimen", last_item, par_shape_dimen_code);

```

1670. ⟨Cases of *last_item* for *print_cmd_chr* 1647⟩ +=
par_shape_length_code: *print_esc*("parshapelength");
par_shape_indent_code: *print_esc*("parshapeindent");
par_shape_dimen_code: *print_esc*("parshapedimen");

1671. \langle Cases for fetching a dimension value 1668 $\rangle + \equiv$
 $par_shape_length_code, par_shape_indent_code, par_shape_dimen_code:$ **begin**
 $q \leftarrow cur_chr - par_shape_length_code; scan_int;$
if $(par_shape_ptr = null) \vee (cur_val \leq 0)$ **then** $cur_val \leftarrow 0$
else begin if $q = 2$ **then**
 $begin\ q \leftarrow cur_val \bmod 2; cur_val \leftarrow (cur_val + q) \operatorname{div} 2;$
end;
if $cur_val > info(par_shape_ptr)$ **then** $cur_val \leftarrow info(par_shape_ptr);$
 $cur_val \leftarrow mem[par_shape_ptr + 2 * cur_val - q].sc;$
end;
 $cur_val_level \leftarrow dimen_val;$
end;

1672. The `\showgroups` command displays all currently active grouping levels.

define $show_groups = 4$ { `\showgroups` }
 \langle Generate all ε -TeX primitives 1646 $\rangle + \equiv$
 $primitive("showgroups", xray, show_groups);$

1673. \langle Cases of $xray$ for $print_cmd_chr$ 1673 $\rangle \equiv$
 $show_groups: print_esc("showgroups");$

See also sections 1682 and 1687.

This code is used in section 1468.

1674. \langle Cases for $show_whatever$ 1674 $\rangle \equiv$
 $show_groups: begin_diagnostic; show_save_groups;$
end;

See also section 1688.

This code is used in section 1469.

1675. \langle Types in the outer block 18 $\rangle + \equiv$
 $save_pointer = 0 .. save_size; \{ index\ into\ save_stack \}$

1676. The modifications of TeX required for the display produced by the *show_save_groups* procedure were first discussed by Donald E. Knuth in *TUGboat* **11**, 165–170 and 499–511, 1990.

In order to understand a group type we also have to know its mode. Since unrestricted horizontal modes are not associated with grouping, they are skipped when traversing the semantic nest.

(Declare ε -TeX procedures for use by *main_control* 1653) +≡

```

procedure show_save_groups;
  label found1, found2, found, done;
  var p: 0 .. nest_size; { index into nest }
      m: -mmode .. mmode; { mode }
      v: save_pointer; { saved value of save_ptr }
      l: quarterword; { saved value of cur_level }
      c: group_code; { saved value of cur_group }
      a: -1 .. 1; { to keep track of alignments }
      i: integer; j: quarterword; s: str_number;
  begin p ← nest_ptr; nest[p] ← cur_list; { put the top level into the array }
  v ← save_ptr; l ← cur_level; c ← cur_group; save_ptr ← cur_boundary; decr(cur_level);
  a ← 1; print_nl(""); print_ln;
  loop begin print_nl("###"); print_group(true);
    if cur_group = bottom_level then goto done;
    repeat m ← nest[p].mode_field;
      if p > 0 then decr(p)
      else m ← vmode;
    until m ≠ hmode;
    print("□");
    case cur_group of
      simple_group: begin incr(p); goto found2;
      end;
      hbox_group, adjusted_hbox_group: s ← "hbox";
      vbox_group: s ← "vbox";
      vtop_group: s ← "vtop";
      align_group: if a = 0 then
        begin if m = -vmode then s ← "halign"
        else s ← "valign";
        a ← 1; goto found1;
        end
      else begin if a = 1 then print("align□entry")
        else print_esc("cr");
        if p ≥ a then p ← p - a;
        a ← 0; goto found;
        end;
      no_align_group: begin incr(p); a ← -1; print_esc("noalign"); goto found2;
      end;
      output_group: begin print_esc("output"); goto found;
      end;
      math_group: goto found2;
      disc_group, math_choice_group: begin if cur_group = disc_group then print_esc("discretionary")
        else print_esc("mathchoice");
        for i ← 1 to 3 do
          if i ≤ saved(-2) then print("{}");
        goto found2;
        end;
      insert_group: begin if saved(-2) = 255 then print_esc("vadjust")

```

```

    else begin print_esc("insert"); print_int(saved(-2));
      end;
    goto found2;
  end;
vcenter_group: begin s ← "vcenter"; goto found1;
  end;
semi_simple_group: begin incr(p); print_esc("begingroup"); goto found;
  end;
math_shift_group: begin if m = mmode then print_char("$")
  else if nest[p].mode_field = mmode then
    begin print_cmd_chr(eq_no, saved(-2)); goto found;
    end;
  print_char("$"); goto found;
  end;
math_left_group: begin if type(nest[p+1].eTeX_aux_field) = left_noad then print_esc("left")
  else print_esc("middle");
  goto found;
  end;
end; { there are no other cases }
⟨ Show the box context 1678 ⟩;
found1: print_esc(s); ⟨ Show the box packaging info 1677 ⟩;
found2: print_char("{");
found: print_char(")"); decr(cur_level); cur_group ← save_level(save_ptr);
  save_ptr ← save_index(save_ptr)
end;
done: save_ptr ← v; cur_level ← l; cur_group ← c;
end;

```

1677. ⟨ Show the box packaging info 1677 ⟩ ≡

```

if saved(-2) ≠ 0 then
  begin print_char("␣");
  if saved(-3) = exactly then print("to")
  else print("spread");
  print_scaled(saved(-2)); print("pt");
  end

```

This code is used in section 1676.

1678. \langle Show the box context 1678 $\rangle \equiv$

```

i  $\leftarrow$  saved(-4);
if i  $\neq$  0 then
  if i < box_flag then
    begin if abs(nest[p].mode_field) = vmode then j  $\leftarrow$  hmove
    else j  $\leftarrow$  vmove;
    if i > 0 then print_cmd_chr(j, 0)
    else print_cmd_chr(j, 1);
    print_scaled(abs(i)); print("pt");
    end
  else if i < ship_out_flag then
    begin if i  $\geq$  global_box_flag then
      begin print_esc("global"); i  $\leftarrow$  i - (global_box_flag - box_flag);
      end;
      print_esc("setbox"); print_int(i - box_flag); print_char("=");
      end
    else print_cmd_chr(leader_ship, i - (leader_flag - a_leaders))

```

This code is used in section 1676.

1679. The *scan_general_text* procedure is much like *scan_toks*(*false*, *false*), but will be invoked via *expand*, i.e., recursively.

\langle Declare ε -TEX procedures for scanning 1679 $\rangle \equiv$

procedure *scan_general_text*; *forward*;

See also sections 1769, 1778, and 1783.

This code is used in section 435.

1680. The token list (balanced text) created by *scan_general_text* begins at *link(temp_head)* and ends at *cur_val*. (If *cur_val* = *temp_head*, the list is empty.)

⟨Declare ε -TeX procedures for token lists 1680⟩ \equiv

```
procedure scan_general_text;
  label found;
  var s: normal .. absorbing; { to save scanner_status }
    w: pointer; { to save warning_index }
    d: pointer; { to save def_ref }
    p: pointer; { tail of the token list being built }
    q: pointer; { new node being added to the token list via store_new_token }
    unbalance: halfword; { number of unmatched left braces }
  begin s  $\leftarrow$  scanner_status; w  $\leftarrow$  warning_index; d  $\leftarrow$  def_ref; scanner_status  $\leftarrow$  absorbing;
  warning_index  $\leftarrow$  cur_cs; def_ref  $\leftarrow$  get_avail; token_ref_count(def_ref)  $\leftarrow$  null; p  $\leftarrow$  def_ref;
  scan_left_brace; { remove the compulsory left brace }
  unbalance  $\leftarrow$  1;
  loop begin get_token;
    if cur_tok < right_brace_limit then
      if cur_cmd < right_brace then incr(unbalance)
      else begin decr(unbalance);
        if unbalance = 0 then goto found;
      end;
      store_new_token(cur_tok);
    end;
  found: q  $\leftarrow$  link(def_ref); free_avail(def_ref); { discard reference count }
  if q = null then cur_val  $\leftarrow$  temp_head else cur_val  $\leftarrow$  p;
  link(temp_head)  $\leftarrow$  q; scanner_status  $\leftarrow$  s; warning_index  $\leftarrow$  w; def_ref  $\leftarrow$  d;
end;
```

See also section 1750.

This code is used in section 490.

1681. The `\showtokens` command displays a token list.

```
define show_tokens = 5 { \showtokens , must be odd! }
⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩  $+\equiv$ 
  primitive("showtokens", xray, show_tokens);
```

1682. ⟨Cases of *xray* for *print_cmd_chr* 1673⟩ $+\equiv$
show_tokens: *print_esc*("showtokens");

1683. The `\unexpanded` primitive prevents expansion of tokens much as the result from `\the` applied to a token variable. The `\detokenize` primitive converts a token list into a list of character tokens much as if the token list were written to a file. We use the fact that the command modifiers for `\unexpanded` and `\detokenize` are odd whereas those for `\the` and `\showthe` are even.

```
⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩  $+\equiv$ 
  primitive("unexpanded", the, 1);
  primitive("detokenize", the, show_tokens);
```

1684. ⟨Cases of *the* for *print_cmd_chr* 1684⟩ \equiv
else if *chr_code* = 1 **then** *print_esc*("unexpanded")
 else *print_esc*("detokenize")

This code is used in section 288.

1685. \langle Handle `\unexpanded` or `\detokenize` and return 1685 $\rangle \equiv$
if *odd*(*cur_chr*) **then**
 begin *c* \leftarrow *cur_chr*; *scan_general_text*;
 if *c* = 1 **then** *the_toks* \leftarrow *cur_val*
 else begin *old_setting* \leftarrow *selector*; *selector* \leftarrow *new_string*; *b* \leftarrow *pool_ptr*; *p* \leftarrow *get_avail*;
 link(*p*) \leftarrow *link*(*temp_head*); *token_show*(*p*); *flush_list*(*p*); *selector* \leftarrow *old_setting*;
 the_toks \leftarrow *str_toks*(*b*);
 end;
 return;
end

This code is used in section 491.

1686. The `\showifs` command displays all currently active conditionals.

define *show_ifs* = 6 { `\showifs` }
 \langle Generate all ε -TEX primitives 1646 $\rangle + \equiv$
 primitive("showifs", *xray*, *show_ifs*);

1687. \langle Cases of *xray* for *print_cmd_chr* 1673 $\rangle + \equiv$
show_ifs: *print_esc*("showifs");

1688.

define *print_if_line*(#) \equiv
 if # \neq 0 **then**
 begin *print*("_entered_on_line_"); *print_int*(#);
 end
 \langle Cases for *show_whatever* 1674 $\rangle + \equiv$
show_ifs: **begin** *begin_diagnostic*; *print_nl*(""); *print_ln*;
 if *cond_ptr* = *null* **then**
 begin *print_nl*("###_"); *print*("no_active_conditionals");
 end
 else begin *p* \leftarrow *cond_ptr*; *n* \leftarrow 0;
 repeat *incr*(*n*); *p* \leftarrow *link*(*p*); **until** *p* = *null*;
 p \leftarrow *cond_ptr*; *t* \leftarrow *cur_if*; *l* \leftarrow *if_line*; *m* \leftarrow *if_limit*;
 repeat *print_nl*("###_level_"); *print_int*(*n*); *print*(":_"); *print_cmd_chr*(*if_test*, *t*);
 if *m* = *fi_code* **then** *print_esc*("else");
 print_if_line(*l*); *decr*(*n*); *t* \leftarrow *subtype*(*p*); *l* \leftarrow *if_line_field*(*p*); *m* \leftarrow *type*(*p*); *p* \leftarrow *link*(*p*);
 until *p* = *null*;
 end;
end;

1689. The `\interactionmode` primitive allows to query and set the interaction mode.

\langle Generate all ε -TEX primitives 1646 $\rangle + \equiv$
 primitive("interactionmode", *set_page_int*, 2);

1690. \langle Cases of *set_page_int* for *print_cmd_chr* 1690 $\rangle \equiv$
else if *chr_code* = 2 **then** *print_esc*("interactionmode")

This code is used in section 443.

1691. \langle Cases for ‘Fetch the *dead_cycles* or the *insert_penalties*’ 1691 $\rangle \equiv$
else if *m* = 2 **then** *cur_val* \leftarrow *interaction*

This code is used in section 445.

1692. \langle Declare ε -TeX procedures for use by *main_control* 1653 $\rangle + \equiv$
procedure *new_interaction*; *forward*;

1693. \langle Cases for *alter_integer* 1693 $\rangle \equiv$
else if *c* = 2 **then**
 begin if (*cur_val* < *batch_mode*) \vee (*cur_val* > *error_stop_mode*) **then**
 begin *print_err*("Bad_interaction_mode");
 help2("Modes_are_0=batch,_1=nonstop,_2=scroll,_and")
 ("3=errorstop._Proceed,_and_I'll_ignore_this_case."); *int_error*(*cur_val*);
 end
 else begin *cur_chr* \leftarrow *cur_val*; *new_interaction*;
 end;
end

This code is used in section 1422.

1694. The *middle* feature of ε -TeX allows one or several `\middle` delimiters to appear between `\left` and `\right`.

\langle Generate all ε -TeX primitives 1646 $\rangle + \equiv$
 primitive("middle", *left_right*, *middle_noad*);

1695. \langle Cases of *left_right* for *print_cmd_chr* 1695 $\rangle \equiv$
else if *chr_code* = *middle_noad* **then** *print_esc*("middle")

This code is used in section 1365.

1696. In constructions such as

```

\hbox to \hsize{
  \hskip 0pt plus 0.0001fil
  ...
  \hfil\penalty-200\hfilneg
...}

```

the stretch components of `\hfil` and `\hfilneg` compensate; they may, however, get modified in order to prevent arithmetic overflow during *hlist_out* when each of them is multiplied by a large *glue_set* value.

Since this “glue rounding” depends on state variables *cur_g* and *cur_glue* and TEX-**X_{CT}** is supposed to emulate the behavior of TEX-**X_{CT}** (plus a suitable postprocessor) as close as possible the glue rounding cannot be postponed until (segments of) an hlist has been reversed.

The code below is invoked after the effective width, *rule_wd*, of a glue node has been computed. The glue node is either converted into a kern node or, for leaders, the glue specification is replaced by an equivalent rigid one; the subtype of the glue node remains unchanged.

⟨Handle a glue node for mixed direction typesetting 1696⟩ ≡

```

if (((g_sign = stretching) ∧ (stretch_order(g) = g_order)) ∨ ((g_sign = shrinking) ∧ (shrink_order(g) =
  g_order))) then
  begin fast_delete_glue_ref(g);
if subtype(p) < a_leaders then
  begin type(p) ← kern_node; width(p) ← rule_wd;
  end
else begin g ← get_node(glue_spec_size);
  stretch_order(g) ← filll + 1; shrink_order(g) ← filll + 1; { will never match }
  width(g) ← rule_wd; stretch(g) ← 0; shrink(g) ← 0; glue_ptr(p) ← g;
  end;
end

```

This code is used in sections 653, 735, and 1723.

1697. The optional *TeXXeT* feature of ε -TeX contains the code for mixed left-to-right and right-to-left typesetting. This code is inspired by but different from TeX-**XqT** as presented by Donald E. Knuth and Pierre MacKay in *TUGboat* 8, 14–25, 1987.

In order to avoid confusion with TeX-**XqT** the present implementation of mixed direction typesetting is called TeX-**XqT**. It differs from TeX-**XqT** in several important aspects: (1) Right-to-left text is reversed explicitly by the *ship_out* routine and is written to a normal DVI file without any *begin_reflect* or *end_reflect* commands; (2) a *math_node* is (ab)used instead of a *whatsit_node* to record the `\beginL`, `\endL`, `\beginR`, and `\endR` text direction primitives in order to keep the influence on the line breaking algorithm for pure left-to-right text as small as possible; (3) right-to-left text interrupted by a displayed equation is automatically resumed after that equation; and (4) the *valign* command code with a non-zero command modifier is (ab)used for the text direction primitives.

Nevertheless there is a subtle difference between TeX and TeX-**XqT** that may influence the line breaking algorithm for pure left-to-right text. When a paragraph containing math mode material is broken into lines TeX may generate lines where math mode material is not enclosed by properly nested `\mathon` and `\mathoff` nodes. Unboxing such lines as part of a new paragraph may have the effect that hyphenation is attempted for ‘words’ originating from math mode or that hyphenation is inhibited for words originating from horizontal mode.

In TeX-**XqT** additional `\beginM`, resp. `\endM` math nodes are supplied at the start, resp. end of lines such that math mode material inside a horizontal list always starts with either `\mathon` or `\beginM` and ends with `\mathoff` or `\endM`. These additional nodes are transparent to operations such as `\unskip`, `\lastpenalty`, or `\lastbox` but they do have the effect that hyphenation is never attempted for ‘words’ originating from math mode and is never inhibited for words originating from horizontal mode.

```
define TeXXeT_state  $\equiv$  eTeX_state(TeXXeT_code)
define TeXXeT_en  $\equiv$  (TeXXeT_state > 0) {is TeX-XqT enabled?}

⟨Cases for print_param 1656⟩ +=
eTeX_state_code + TeXXeT_code: print_esc("TeXXeTstate");
```

1698. ⟨Generate all ε -TeX primitives 1646⟩ +=

```
primitive("TeXXeTstate", assign_int, eTeX_state_base + TeXXeT_code);
primitive("beginL", valign, begin_L_code); primitive("endL", valign, end_L_code);
primitive("beginR", valign, begin_R_code); primitive("endR", valign, end_R_code);
```

1699. ⟨Cases of *valign* for *print_cmd_chr* 1699⟩ \equiv

```
else case chr_code of
```

```
  begin_L_code: print_esc("beginL");
  end_L_code: print_esc("endL");
  begin_R_code: print_esc("beginR");
  othercases print_esc("endR")
endcases
```

This code is used in section 288.

1700. ⟨Cases of *main_control* for *hmode* + *valign* 1700⟩ \equiv

```
if cur_chr > 0 then
  begin if eTeX_enabled(TeXXeT_en, cur_cmd, cur_chr) then tail_append(new_math(0, cur_chr));
  end
else
```

This code is used in section 1306.

1701. An hbox with subtype dlist will never be reversed, even when embedded in right-to-left text.

\langle Display if this box is never to be reversed 1701 $\rangle \equiv$

```
if (type(p) = hlist_node)  $\wedge$  (box_lr(p) = dlist) then print("_display")
```

This code is used in section 202.

1702. A number of routines are based on a stack of one-word nodes whose *info* fields contain *end_M_code*, *end_L_code*, or *end_R_code*. The top of the stack is pointed to by *LR_ptr*.

When the stack manipulation macros of this section are used below, variable *LR_ptr* might be the global variable declared here for *hpack* and *ship_out*, or might be local to *post_line_break*.

```
define put_LR(#)  $\equiv$ 
  begin temp_ptr  $\leftarrow$  get_avail; info(temp_ptr)  $\leftarrow$  #; link(temp_ptr)  $\leftarrow$  LR_ptr;
  LR_ptr  $\leftarrow$  temp_ptr;
end
define push_LR(#)  $\equiv$  put_LR(end_LR_type(#))
define pop_LR  $\equiv$ 
  begin temp_ptr  $\leftarrow$  LR_ptr; LR_ptr  $\leftarrow$  link(temp_ptr); free_avail(temp_ptr);
end
```

\langle Global variables 13 $\rangle + \equiv$

LR_ptr: pointer; { stack of LR codes for *hpack*, *ship_out*, and *init_math* }

LR_problems: integer; { counts missing begins and ends }

cur_dir: small_number; { current text direction }

1703. \langle Set initial values of key variables 21 $\rangle + \equiv$

```
LR_ptr  $\leftarrow$  null; LR_problems  $\leftarrow$  0; cur_dir  $\leftarrow$  left_to_right;
```

1704. \langle Insert LR nodes at the beginning of the current line and adjust the LR stack based on LR nodes in this line 1704 $\rangle \equiv$

```
begin q  $\leftarrow$  link(temp_head);
if LR_ptr  $\neq$  null then
  begin temp_ptr  $\leftarrow$  LR_ptr; r  $\leftarrow$  q;
  repeat s  $\leftarrow$  new_math(0, begin_LR_type(info(temp_ptr))); link(s)  $\leftarrow$  r; r  $\leftarrow$  s;
    temp_ptr  $\leftarrow$  link(temp_ptr);
  until temp_ptr = null;
  link(temp_head)  $\leftarrow$  r;
end;
while q  $\neq$  cur_break(cur_p) do
  begin if  $\neg$ is_char_node(q) then
    if type(q) = math_node then  $\langle$  Adjust the LR stack for the post_line_break routine 1705  $\rangle$ ;
    q  $\leftarrow$  link(q);
  end;
end
```

This code is used in section 1054.

1705. \langle Adjust the LR stack for the *post_line_break* routine 1705 $\rangle \equiv$

```
if end_LR(q) then
  begin if LR_ptr  $\neq$  null then
    if info(LR_ptr) = end_LR_type(q) then pop_LR;
  end
else push_LR(q)
```

This code is used in sections 1053, 1055, and 1704.

1706. We use the fact that q now points to the node with `\rightskip` glue.

\langle Insert LR nodes at the end of the current line 1706 $\rangle \equiv$

```

if  $LR\_ptr \neq null$  then
  begin  $s \leftarrow temp\_head$ ;  $r \leftarrow link(s)$ ;
  while  $r \neq q$  do
    begin  $s \leftarrow r$ ;  $r \leftarrow link(s)$ ;
    end;
   $r \leftarrow LR\_ptr$ ;
  while  $r \neq null$  do
    begin  $temp\_ptr \leftarrow new\_math(0, info(r))$ ;  $link(s) \leftarrow temp\_ptr$ ;  $s \leftarrow temp\_ptr$ ;  $r \leftarrow link(r)$ ;
    end;
   $link(s) \leftarrow q$ ;
end

```

This code is used in section 1054.

1707. \langle Initialize the LR stack 1707 $\rangle \equiv$
 $put_LR(before)$ { this will never match }

This code is used in sections 821, 1711, and 1731.

1708. \langle Adjust the LR stack for the $hpack$ routine 1708 $\rangle \equiv$

```

if  $end\_LR(p)$  then
  if  $info(LR\_ptr) = end\_LR\_type(p)$  then  $pop\_LR$ 
  else begin  $incr(LR\_problems)$ ;  $type(p) \leftarrow kern\_node$ ;  $subtype(p) \leftarrow explicit$ ;
  end
else  $push\_LR(p)$ 

```

This code is used in section 823.

1709. \langle Check for LR anomalies at the end of $hpack$ 1709 $\rangle \equiv$

```

begin if  $info(LR\_ptr) \neq before$  then
  begin while  $link(q) \neq null$  do  $q \leftarrow link(q)$ ;
  repeat  $temp\_ptr \leftarrow q$ ;  $q \leftarrow new\_math(0, info(LR\_ptr))$ ;  $link(temp\_ptr) \leftarrow q$ ;
     $LR\_problems \leftarrow LR\_problems + 10000$ ;  $pop\_LR$ ;
  until  $info(LR\_ptr) = before$ ;
  end;
if  $LR\_problems > 0$  then
  begin  $\langle$  Report LR problems 1710  $\rangle$ ;
  goto  $common\_ending$ ;
  end;
 $pop\_LR$ ;
if  $LR\_ptr \neq null$  then  $confusion("LR1")$ ;
end

```

This code is used in section 821.

1710. \langle Report LR problems 1710 $\rangle \equiv$

```

begin  $print\_nl$ ;  $print\_nl("\endL\_or\_endR\_problem\_")$ ;
 $print\_int(LR\_problems \text{ div } 10000)$ ;  $print("\_missing\_")$ ;
 $print\_int(LR\_problems \text{ mod } 10000)$ ;  $print("\_extra")$ ;
 $LR\_problems \leftarrow 0$ ;
end

```

This code is used in sections 1709 and 1727.

1711. \langle Initialize *hlist_out* for mixed direction typesetting 1711 $\rangle \equiv$
if *eTeX_ex* **then**
 begin \langle Initialize the LR stack 1707 \rangle ;
 if *box_lr*(*this_box*) = *dlist* **then**
 if *cur_dir* = *right_to_left* **then**
 begin *cur_dir* \leftarrow *left_to_right*; *cur_h* \leftarrow *cur_h* - *width*(*this_box*);
 end
 else *set_box_lr*(*this_box*)(0);
 if (*cur_dir* = *right_to_left*) \wedge (*box_lr*(*this_box*) \neq *reversed*) **then**
 \langle Reverse the complete hlist and set the subtype to *reversed* 1718 \rangle ;
 end

This code is used in sections 647 and 729.

1712. \langle Finish *hlist_out* for mixed direction typesetting 1712 $\rangle \equiv$
if *eTeX_ex* **then**
 begin \langle Check for LR anomalies at the end of *hlist_out* 1715 \rangle ;
 if *box_lr*(*this_box*) = *dlist* **then** *cur_dir* \leftarrow *right_to_left*;
 end

This code is used in sections 647 and 729.

1713. \langle Handle a math node in *hlist_out* 1713 $\rangle \equiv$
 begin if *eTeX_ex* **then** \langle Adjust the LR stack for the *hlist_out* routine; if necessary reverse an hlist segment and **goto** *reswitch* 1714 \rangle ;
 cur_h \leftarrow *cur_h* + *width*(*p*);
 end

This code is used in sections 650 and 732.

1714. Breaking a paragraph into lines while TEX-~~X~~_qT is disabled may result in lines with unpaired math nodes. Such hlists are silently accepted in the absence of text direction directives.

define *LR_dir*(#) \equiv (*subtype*(#) **div** *R_code*) { text direction of a ‘math node’ }
 \langle Adjust the LR stack for the *hlist_out* routine; if necessary reverse an hlist segment and **goto** *reswitch* 1714 $\rangle \equiv$
begin if *end_LR*(*p*) **then**
 if *info*(*LR_ptr*) = *end_LR_type*(*p*) **then** *pop_LR*
 else begin if *subtype*(*p*) > *L_code* **then** *incr*(*LR_problems*);
 end
else begin *push_LR*(*p*);
 if *LR_dir*(*p*) \neq *cur_dir* **then** \langle Reverse an hlist segment and **goto** *reswitch* 1719 \rangle ;
 end;
 type(*p*) \leftarrow *kern_node*;
end

This code is used in section 1713.

1715. \langle Check for LR anomalies at the end of *hlist_out* 1715 $\rangle \equiv$
 begin while *info*(*LR_ptr*) \neq *before* **do**
 begin if *info*(*LR_ptr*) > *L_code* **then** *LR_problems* \leftarrow *LR_problems* + 10000;
 pop_LR;
 end;
 pop_LR;
end

This code is used in section 1712.

1716. **define** *edge_node* = *style_node* { a *style_node* does not occur in hlists }
define *edge_node_size* = *style_node_size* { number of words in an edge node }
define *edge_dist*(#) \equiv *depth*(#)
{ new *left_edge* position relative to *cur_h* (after *width* has been taken into account) }

\langle Declare procedures needed in *hlist_out*, *vlist_out* 1612 $\rangle + \equiv$

function *new_edge*(*s* : *small_number*; *w* : *scaled*): *pointer*; { create an edge node }
var *p*: *pointer*; { the new node }
begin *p* \leftarrow *get_node*(*edge_node_size*); *type*(*p*) \leftarrow *edge_node*; *subtype*(*p*) \leftarrow *s*; *width*(*p*) \leftarrow *w*;
edge_dist(*p*) \leftarrow 0; { the *edge_dist* field will be set later }
new_edge \leftarrow *p*;
end;

1717. \langle Cases of *hlist_out* that arise in mixed direction text only 1717 $\rangle \equiv$
edge_node: **begin** *cur_h* \leftarrow *cur_h* + *width*(*p*); *left_edge* \leftarrow *cur_h* + *edge_dist*(*p*); *cur_dir* \leftarrow *subtype*(*p*);
end;

This code is used in sections 650 and 732.

1718. We detach the hlist, start a new one consisting of just one kern node, append the reversed list, and set the width of the kern node.

\langle Reverse the complete hlist and set the subtype to *reversed* 1718 $\rangle \equiv$
begin *save_h* \leftarrow *cur_h*; *temp_ptr* \leftarrow *p*; *p* \leftarrow *new_kern*(0); *link*(*prev_p*) \leftarrow *p*; *cur_h* \leftarrow 0;
link(*p*) \leftarrow *reverse*(*this_box*, null, *cur_g*, *cur_glue*); *width*(*p*) \leftarrow -*cur_h*; *cur_h* \leftarrow *save_h*;
set_box_lr(*this_box*)(*reversed*);
end

This code is used in section 1711.

1719. We detach the remainder of the hlist, replace the math node by an edge node, and append the reversed hlist segment to it; the tail of the reversed segment is another edge node and the remainder of the original list is attached to it.

\langle Reverse an hlist segment and **goto** *reswitch* 1719 $\rangle \equiv$
begin *save_h* \leftarrow *cur_h*; *temp_ptr* \leftarrow *link*(*p*); *rule_wd* \leftarrow *width*(*p*); *free_node*(*p*, *small_node_size*);
cur_dir \leftarrow *reflected*; *p* \leftarrow *new_edge*(*cur_dir*, *rule_wd*); *link*(*prev_p*) \leftarrow *p*;
cur_h \leftarrow *cur_h* - *left_edge* + *rule_wd*; *link*(*p*) \leftarrow *reverse*(*this_box*, *new_edge*(*reflected*, 0), *cur_g*, *cur_glue*);
edge_dist(*p*) \leftarrow *cur_h*; *cur_dir* \leftarrow *reflected*; *cur_h* \leftarrow *save_h*; **goto** *reswitch*;
end

This code is used in section 1714.

1720. The *reverse* function defined here is responsible to reverse the nodes of an hlist (segment). The first parameter *this_box* is the enclosing hlist node, the second parameter *t* is to become the tail of the reversed list, and the global variable *temp_ptr* is the head of the list to be reversed. Finally *cur_g* and *cur_glue* are the current glue rounding state variables, to be updated by this function. We remove nodes from the original list and add them to the head of the new one.

⟨Declare procedures needed in *hlist_out*, *vlist_out* 1612⟩ +≡

```
function reverse(this_box, t : pointer; var cur_g : scaled; var cur_glue : real): pointer;
  label reswitch, next_p, done;
  var l: pointer; { the new list }
  p: pointer; { the current node }
  q: pointer; { the next node }
  g_order: glue_ord; { applicable order of infinity for glue }
  g_sign: normal .. shrinking; { selects type of glue }
  glue_temp: real; { glue value before rounding }
  m, n: halfword; { count of unmatched math nodes }
begin g_order ← glue_order(this_box); g_sign ← glue_sign(this_box); l ← t; p ← temp_ptr;
m ← min_halfword; n ← min_halfword;
loop begin while p ≠ null do ⟨Move node p to the new list and go to the next node; or goto done if
  the end of the reflected segment has been reached 1721⟩;
  if (t = null) ∧ (m = min_halfword) ∧ (n = min_halfword) then goto done;
  p ← new_math(0, info(LR_ptr)); LR_problems ← LR_problems + 10000;
  { manufacture one missing math node }
  end;
done: reverse ← l;
end;
```

1721. ⟨Move node *p* to the new list and go to the next node; or **goto** *done* if the end of the reflected segment has been reached 1721⟩ ≡

```
reswitch: if is_char_node(p) then
  repeat f ← font(p); c ← character(p); cur_h ← cur_h + char_width(f)(char_info(f)(c)); q ← link(p);
  link(p) ← l; l ← p; p ← q;
  until ¬is_char_node(p)
else ⟨Move the non-char_node p to the new list 1722⟩
```

This code is used in section 1720.

1722. ⟨Move the non-*char_node* *p* to the new list 1722⟩ ≡

```
begin q ← link(p);
case type(p) of
  hlist_node, vlist_node, rule_node, kern_node: rule_wd ← width(p);
  ⟨Cases of reverse that need special treatment 1723⟩
  edge_node: confusion("LR2");
othercases goto next_p
endcases;
cur_h ← cur_h + rule_wd;
next_p: link(p) ← l;
if type(p) = kern_node then
  if (rule_wd = 0) ∨ (l = null) then
    begin free_node(p, small_node_size); p ← l;
    end;
  l ← p; p ← q;
end
```

This code is used in section 1721.

1723. Here we compute the effective width of a glue node as in *hlist.out*.

\langle Cases of *reverse* that need special treatment 1723 $\rangle \equiv$
glue_node: **begin** *round_glue*; \langle Handle a glue node for mixed direction typesetting 1696 \rangle ;
end;

See also sections 1724 and 1725.

This code is used in section 1722.

1724. A ligature node is replaced by a char node.

\langle Cases of *reverse* that need special treatment 1723 $\rangle + \equiv$
ligature_node: **begin** *flush_node_list*(*lig_ptr*(*p*)); *temp_ptr* \leftarrow *p*; *p* \leftarrow *get_avail*;
mem[*p*] \leftarrow *mem*[*lig_char*(*temp_ptr*)]; *link*(*p*) \leftarrow *q*; *free_node*(*temp_ptr*, *small_node_size*); **goto** *reswitch*;
end;

1725. Math nodes in an inner reflected segment are modified, those at the outer level are changed into kern nodes.

\langle Cases of *reverse* that need special treatment 1723 $\rangle + \equiv$
math_node: **begin** *rule_wd* \leftarrow *width*(*p*);
if *end_LR*(*p*) **then**
if *info*(*LR_ptr*) \neq *end_LR_type*(*p*) **then**
begin *type*(*p*) \leftarrow *kern_node*; *incr*(*LR_problems*);
end
else begin *pop_LR*;
if *n* > *min_halfword* **then**
begin *decr*(*n*); *decr*(*subtype*(*p*)); { change *after* into *before* }
end
else begin *type*(*p*) \leftarrow *kern_node*;
if *m* > *min_halfword* **then** *decr*(*m*)
else \langle Finish the reversed hlist segment and **goto** *done* 1726 \rangle ;
end;
end
else begin *push_LR*(*p*);
if (*n* > *min_halfword*) \vee (*LR_dir*(*p*) \neq *cur_dir*) **then**
begin *incr*(*n*); *incr*(*subtype*(*p*)); { change *before* into *after* }
end
else begin *type*(*p*) \leftarrow *kern_node*; *incr*(*m*);
end;
end;
end;

1726. Finally we have found the end of the hlist segment to be reversed; the final math node is released and the remaining list attached to the edge node terminating the reversed segment.

\langle Finish the reversed hlist segment and **goto** *done* 1726 $\rangle \equiv$
begin *free_node*(*p*, *small_node_size*); *link*(*t*) \leftarrow *q*; *width*(*t*) \leftarrow *rule_wd*; *edge_dist*(*t*) \leftarrow $-cur_h - rule_wd$;
goto *done*;
end

This code is used in section 1725.

1727. \langle Check for LR anomalies at the end of *ship_out* 1727 $\rangle \equiv$
begin if *LR_problems* > 0 **then**
 begin \langle Report LR problems 1710 \rangle ;
 print_char(""); *print_ln*;
 end;
if (*LR_ptr* \neq *null*) \vee (*cur_dir* \neq *left_to_right*) **then** *confusion*("LR3");
end

This code is used in sections 666 and 750.

1728. Some special actions are required for displayed equation in paragraphs with mixed direction texts. First of all we have to set the text direction preceding the display.

\langle Set the value of *x* to the text direction before the display 1728 $\rangle \equiv$
 if *LR_save* = *null* **then** *x* \leftarrow 0
 else if *info*(*LR_save*) \geq *R_code* **then** *x* \leftarrow -1 **else** *x* \leftarrow 1

This code is used in sections 1729 and 1731.

1729. \langle Prepare for display after an empty paragraph 1729 $\rangle \equiv$
 begin *pop_nest*; \langle Set the value of *x* to the text direction before the display 1728 \rangle ;
 end

This code is used in section 1321.

1730. When calculating the natural width, w , of the final line preceding the display, we may have to copy all or part of its hlist. We copy, however, only those parts of the original list that are relevant for the computation of *pre_display_size*.

⟨Declare subprocedures for *init_math* 1730⟩ ≡

```
procedure just_copy( $p, h, t : \text{pointer}$ );
  label found, not_found;
  var  $r : \text{pointer}$ ; { current node being fabricated for new list }
       $words : 0 \dots 5$ ; { number of words remaining to be copied }
  begin while  $p \neq \text{null}$  do
    begin  $words \leftarrow 1$ ; { this setting occurs in more branches than any other }
    if is_char_node( $p$ ) then  $r \leftarrow \text{get\_avail}$ 
    else case type( $p$ ) of
      hlist_node, vlist_node: begin  $r \leftarrow \text{get\_node}(\text{box\_node\_size})$ ;  $\text{mem}[r + 6] \leftarrow \text{mem}[p + 6]$ ;
         $\text{mem}[r + 5] \leftarrow \text{mem}[p + 5]$ ; { copy the last two words }
         $words \leftarrow 5$ ;  $\text{list\_ptr}(r) \leftarrow \text{null}$ ; { this affects  $\text{mem}[r + 5]$  }
      end;
      rule_node: begin  $r \leftarrow \text{get\_node}(\text{rule\_node\_size})$ ;  $words \leftarrow \text{rule\_node\_size}$ ;
      end;
      ligature_node: begin  $r \leftarrow \text{get\_avail}$ ; { only font and character are needed }
         $\text{mem}[r] \leftarrow \text{mem}[\text{lig\_char}(p)]$ ; goto found;
      end;
      kern_node, math_node: begin  $r \leftarrow \text{get\_node}(\text{small\_node\_size})$ ;  $words \leftarrow \text{small\_node\_size}$ ;
      end;
      glue_node: begin  $r \leftarrow \text{get\_node}(\text{small\_node\_size})$ ;  $\text{add\_glue\_ref}(\text{glue\_ptr}(p))$ ;
         $\text{glue\_ptr}(r) \leftarrow \text{glue\_ptr}(p)$ ;  $\text{leader\_ptr}(r) \leftarrow \text{null}$ ;
      end;
      whatsit_node: ⟨Make a partial copy of the whatsit node  $p$  and make  $r$  point to it; set  $words$  to the
        number of initial words not yet copied 1601⟩;
    othercases goto not_found
  endcases;
  while  $words > 0$  do
    begin decr( $words$ );  $\text{mem}[r + words] \leftarrow \text{mem}[p + words]$ ;
    end;
  found:  $\text{link}(h) \leftarrow r$ ;  $h \leftarrow r$ ;
  not_found:  $p \leftarrow \text{link}(p)$ ;
  end;
   $\text{link}(h) \leftarrow t$ ;
end;
```

See also section 1735.

This code is used in section 1314.

1731. When the final line ends with R-text, the value w refers to the line reflected with respect to the left edge of the enclosing vertical list.

```

⟨Prepare for display after a non-empty paragraph 1731⟩ ≡
  if eTeX_ex then ⟨Let  $j$  be the prototype box for the display 1737⟩;
   $v \leftarrow \text{shift\_amount}(\text{just\_box})$ ; ⟨Set the value of  $x$  to the text direction before the display 1728⟩;
  if  $x \geq 0$  then
    begin  $p \leftarrow \text{list\_ptr}(\text{just\_box})$ ;  $\text{link}(\text{temp\_head}) \leftarrow \text{null}$ ;
    end
  else begin  $v \leftarrow -v - \text{width}(\text{just\_box})$ ;  $p \leftarrow \text{new\_math}(0, \text{begin\_L\_code})$ ;  $\text{link}(\text{temp\_head}) \leftarrow p$ ;
     $\text{just\_copy}(\text{list\_ptr}(\text{just\_box}), p, \text{new\_math}(0, \text{end\_L\_code}))$ ;  $\text{cur\_dir} \leftarrow \text{right\_to\_left}$ ;
    end;
   $v \leftarrow v + 2 * \text{quad}(\text{cur\_font})$ ;
  if TeXXeT.en then ⟨Initialize the LR stack 1707⟩

```

This code is used in section 1322.

```

1732. ⟨Finish the natural width computation 1732⟩ ≡
  if TeXXeT.en then
    begin while  $\text{LR\_ptr} \neq \text{null}$  do  $\text{pop\_LR}$ ;
    if  $\text{LR\_problems} \neq 0$  then
      begin  $w \leftarrow \text{max\_dimen}$ ;  $\text{LR\_problems} \leftarrow 0$ ;
      end;
    end;
     $\text{cur\_dir} \leftarrow \text{left\_to\_right}$ ;  $\text{flush\_node\_list}(\text{link}(\text{temp\_head}))$ 

```

This code is used in section 1322.

1733. In the presence of text direction directives we assume that any LR problems have been fixed by the *hpack* routine. If the final line contains, however, text direction directives while TeX--XqT is disabled, then we set $w \leftarrow \text{max_dimen}$.

```

⟨Cases of ‘Let  $d$  be the natural width’ that need special treatment 1733⟩ ≡
 $\text{math\_node}$ : begin  $d \leftarrow \text{width}(p)$ ;
  if TeXXeT.en then ⟨Adjust the LR stack for the init\_math routine 1734⟩
  else if  $\text{subtype}(p) \geq \text{L\_code}$  then
    begin  $w \leftarrow \text{max\_dimen}$ ; goto done;
    end;
  end;
 $\text{edge\_node}$ : begin  $d \leftarrow \text{width}(p)$ ;  $\text{cur\_dir} \leftarrow \text{subtype}(p)$ ;
  end;

```

This code is used in section 1323.

1734. \langle Adjust the LR stack for the *init_math* routine 1734 $\rangle \equiv$

```

if end_LR(p) then
  begin if info(LR_ptr) = end_LR_type(p) then pop_LR
  else if subtype(p) > L_code then
    begin w  $\leftarrow$  max_dimen; goto done;
    end
  end
else begin push_LR(p);
  if LR_dir(p)  $\neq$  cur_dir then
    begin just_reverse(p); p  $\leftarrow$  temp_head;
    end;
  end

```

This code is used in section 1733.

1735. \langle Declare subprocedures for *init_math* 1730 $\rangle + \equiv$

```

procedure just_reverse(p : pointer);
  label found, done;
  var l: pointer; { the new list }
      t: pointer; { tail of reversed segment }
      q: pointer; { the next node }
      m, n: halfword; { count of unmatched math nodes }
  begin m  $\leftarrow$  min_halfword; n  $\leftarrow$  min_halfword;
  if link(temp_head) = null then
    begin just_copy(link(p), temp_head, null); q  $\leftarrow$  link(temp_head);
    end
  else begin q  $\leftarrow$  link(p); link(p)  $\leftarrow$  null; flush_node_list(link(temp_head));
  end;
  t  $\leftarrow$  new_edge(cur_dir, 0); l  $\leftarrow$  t; cur_dir  $\leftarrow$  reflected;
  while q  $\neq$  null do
    if is_char_node(q) then
      repeat p  $\leftarrow$  q; q  $\leftarrow$  link(p); link(p)  $\leftarrow$  l; l  $\leftarrow$  p;
      until  $\neg$ is_char_node(q)
    else begin p  $\leftarrow$  q; q  $\leftarrow$  link(p);
      if type(p) = math_node then  $\langle$  Adjust the LR stack for the just_reverse routine 1736  $\rangle$ ;
      link(p)  $\leftarrow$  l; l  $\leftarrow$  p;
    end;
    goto done;
  found: width(t)  $\leftarrow$  width(p); link(t)  $\leftarrow$  q; free_node(p, small_node_size);
  done: link(temp_head)  $\leftarrow$  l;
  end;

```

1736. \langle Adjust the LR stack for the *just_reverse* routine 1736 $\rangle \equiv$

```

if end_LR(p) then
  if info(LR_ptr)  $\neq$  end_LR_type(p) then
    begin type(p)  $\leftarrow$  kern_node; incr(LR_problems);
    end
  else begin pop_LR;
    if n > min_halfword then
      begin decr(n); decr(subtype(p)); { change after into before }
      end
    else begin if m > min_halfword then decr(m) else goto found;
      type(p)  $\leftarrow$  kern_node;
      end;
    end
  else begin push_LR(p);
    if (n > min_halfword)  $\vee$  (LR_dir(p)  $\neq$  cur_dir) then
      begin incr(n); incr(subtype(p)); { change before into after }
      end
    else begin type(p)  $\leftarrow$  kern_node; incr(m);
      end;
    end

```

This code is used in section 1735.

1737. The prototype box is an hlist node with the width, glue set, and shift amount of *just_box*, i.e., the last line preceding the display. Its hlist reflects the current $\backslash\text{leftskip}$ and $\backslash\text{rightskip}$.

\langle Let *j* be the prototype box for the display 1737 $\rangle \equiv$

```

begin if right_skip = zero_glue then j  $\leftarrow$  new_kern(0)
else j  $\leftarrow$  new_param_glue(right_skip_code);
if left_skip = zero_glue then p  $\leftarrow$  new_kern(0)
else p  $\leftarrow$  new_param_glue(left_skip_code);
link(p)  $\leftarrow$  j; j  $\leftarrow$  new_null_box; width(j)  $\leftarrow$  width(just_box); shift_amount(j)  $\leftarrow$  shift_amount(just_box);
list_ptr(j)  $\leftarrow$  p; glue_order(j)  $\leftarrow$  glue_order(just_box); glue_sign(j)  $\leftarrow$  glue_sign(just_box);
glue_set(j)  $\leftarrow$  glue_set(just_box);
end

```

This code is used in section 1731.

1738. At the end of a displayed equation we retrieve the prototype box.

\langle Local variables for finishing a displayed formula 1374 $\rangle + \equiv$

j: *pointer*; { prototype box }

1739. \langle Retrieve the prototype box 1739 $\rangle \equiv$

```

if mode = mmode then j  $\leftarrow$  LR_box

```

This code is used in sections 1370 and 1370.

1740. \langle Flush the prototype box 1740 $\rangle \equiv$

```

flush_node_list(j)

```

This code is used in section 1375.

1741. The *app_display* procedure used to append the displayed equation and/or equation number to the current vertical list has three parameters: the prototype box, the hbox to be appended, and the displacement of the hbox in the display line.

```

⟨Declare subprocedures for after_math 1741⟩ ≡
procedure app_display(j, b : pointer; d : scaled);
  var z : scaled; { width of the line }
  s : scaled; { move the line right this much }
  e : scaled; { distance from right edge of box to end of line }
  x : integer; { pre_display_direction }
  p, q, r, t, u : pointer; { for list manipulation }
begin s ← display_indent; x ← pre_display_direction;
if x = 0 then shift_amount(b) ← s + d
else begin z ← display_width; p ← b; ⟨Set up the hlist for the display line 1742⟩;
  ⟨Package the display line 1743⟩;
end;
  append_to_vlist(b);
end;

```

This code is used in section 1370.

1742. Here we construct the hlist for the display, starting with node *p* and ending with node *q*. We also set *d* and *e* to the amount of kerning to be added before and after the hlist (adjusted for the prototype box).

```

⟨Set up the hlist for the display line 1742⟩ ≡
if x > 0 then e ← z - d - width(p)
else begin e ← d; d ← z - e - width(p);
  end;
if j ≠ null then
  begin b ← copy_node_list(j); height(b) ← height(p); depth(b) ← depth(p); s ← s - shift_amount(b);
  d ← d + s; e ← e + width(b) - z - s;
  end;
if box_lr(p) = dlist then q ← p { display or equation number }
else begin { display and equation number }
  r ← list_ptr(p); free_node(p, box_node_size);
  if r = null then confusion("LR4");
  if x > 0 then
    begin p ← r;
    repeat q ← r; r ← link(r); { find tail of list }
    until r = null;
    end
  else begin p ← null; q ← r;
    repeat t ← link(r); link(r) ← p; p ← r; r ← t; { reverse list }
    until r = null;
    end;
  end

```

This code is used in section 1741.

1743. In the presence of a prototype box we use its shift amount and width to adjust the values of kerning and add these values to the glue nodes inserted to cancel the `\leftskip` and `\rightskip`. If there is no prototype box (because the display is preceded by an empty paragraph), or if the skip parameters are zero, we just add kerns.

The `cancel_glue` macro creates and links a glue node that is, together with another glue node, equivalent to a given amount of kerning. We can use j as temporary pointer, since all we need is $j \neq \text{null}$.

```

define cancel_glue( $\#$ )  $\equiv j \leftarrow \text{new\_skip\_param}(\#)$ ; cancel_glue_cont
define cancel_glue_cont( $\#$ )  $\equiv \text{link}(\#) \leftarrow j$ ; cancel_glue_cont_cont
define cancel_glue_cont_cont( $\#$ )  $\equiv \text{link}(j) \leftarrow \#$ ; cancel_glue_end
define cancel_glue_end( $\#$ )  $\equiv j \leftarrow \text{glue\_ptr}(\#)$ ; cancel_glue_end_end
define cancel_glue_end_end( $\#$ )  $\equiv \text{stretch\_order}(\text{temp\_ptr}) \leftarrow \text{stretch\_order}(j)$ ;
    shrink_order(temp_ptr)  $\leftarrow \text{shrink\_order}(j)$ ; width(temp_ptr)  $\leftarrow \# - \text{width}(j)$ ;
    stretch(temp_ptr)  $\leftarrow -\text{stretch}(j)$ ; shrink(temp_ptr)  $\leftarrow -\text{shrink}(j)$ 

⟨Package the display line 1743⟩  $\equiv$ 
if  $j = \text{null}$  then
    begin  $r \leftarrow \text{new\_kern}(0)$ ;  $t \leftarrow \text{new\_kern}(0)$ ; { the widths will be set later }
    end
else begin  $r \leftarrow \text{list\_ptr}(b)$ ;  $t \leftarrow \text{link}(r)$ ;
    end;
 $u \leftarrow \text{new\_math}(0, \text{end\_M\_code})$ ;
if  $\text{type}(t) = \text{glue\_node}$  then {  $t$  is \rightskip glue }
    begin cancel_glue(right_skip_code)(q)(u)(t)(e);  $\text{link}(u) \leftarrow t$ ;
    end
else begin  $\text{width}(t) \leftarrow e$ ;  $\text{link}(t) \leftarrow u$ ;  $\text{link}(q) \leftarrow t$ ;
    end;
 $u \leftarrow \text{new\_math}(0, \text{begin\_M\_code})$ ;
if  $\text{type}(r) = \text{glue\_node}$  then {  $r$  is \leftskip glue }
    begin cancel_glue(left_skip_code)(u)(p)(r)(d);  $\text{link}(r) \leftarrow u$ ;
    end
else begin  $\text{width}(r) \leftarrow d$ ;  $\text{link}(r) \leftarrow p$ ;  $\text{link}(u) \leftarrow r$ ;
    if  $j = \text{null}$  then
        begin  $b \leftarrow \text{hpack}(u, \text{natural})$ ;  $\text{shift\_amount}(b) \leftarrow s$ ;
        end
    else  $\text{list\_ptr}(b) \leftarrow u$ ;
    end

```

This code is used in section 1741.

1744. The `scan_tokens` feature of ε -TeX defines the `\scantokens` primitive.

```

⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩  $+\equiv$ 
    primitive("scantokens", input, 2);

```

```

1745. ⟨Cases of input for print_cmd_chr 1745⟩  $\equiv$ 
else if  $\text{chr\_code} = 2$  then print_esc("scantokens")

```

This code is used in section 403.

```

1746. ⟨Cases for input 1746⟩  $\equiv$ 
else if  $\text{cur\_chr} = 2$  then pseudo_start

```

This code is used in section 404.

1747. The global variable *pseudo_files* is used to maintain a stack of pseudo files. The *info* field of each pseudo file points to a linked list of variable size nodes representing lines not yet processed: the *info* field of the first word contains the size of this node, all the following words contain ASCII codes.

⟨Global variables 13⟩ +≡
pseudo_files: *pointer*; { stack of pseudo files }

1748. ⟨Set initial values of key variables 21⟩ +≡
pseudo_files \leftarrow *null*;

1749. The *pseudo_start* procedure initiates reading from a pseudo file.

⟨Declare ε -TeX procedures for expanding 1749⟩ ≡

procedure *pseudo_start*; *forward*;

See also sections 1807, 1812, and 1816.

This code is used in section 388.

1750. ⟨Declare ε -TeX procedures for token lists 1680⟩ +≡

procedure *pseudo_start*;

var *old_setting*: 0 .. *max_selector*; { holds *selector* setting }
s: *str_number*; { string to be converted into a pseudo file }
l, m: *pool_pointer*; { indices into *str_pool* }
p, q, r: *pointer*; { for list construction }
w: *four_quarters*; { four ASCII codes }
nl, sz: *integer*;

begin *scan_general_text*; *old_setting* \leftarrow *selector*; *selector* \leftarrow *new_string*; *token_show*(*temp_head*);
selector \leftarrow *old_setting*; *flush_list*(*link*(*temp_head*)); *str_room*(1); *s* \leftarrow *make_string*;

⟨Convert string *s* into a new pseudo file 1751⟩;
flush_string; ⟨Initiate input from new pseudo file 1752⟩;
end;

1751. \langle Convert string s into a new pseudo file 1751 $\rangle \equiv$
 $str_pool[pool_ptr] \leftarrow si("_"); l \leftarrow str_start[s]; nl \leftarrow si(new_line_char); p \leftarrow get_avail; q \leftarrow p;$
while $l < pool_ptr$ **do**
 begin $m \leftarrow l;$
 while $(l < pool_ptr) \wedge (str_pool[l] \neq nl)$ **do** $incr(l);$
 $sz \leftarrow (l - m + 7) \text{ div } 4;$
 if $sz = 1$ **then** $sz \leftarrow 2;$
 $r \leftarrow get_node(sz); link(q) \leftarrow r; q \leftarrow r; info(q) \leftarrow hi(sz);$
 while $sz > 2$ **do**
 begin $decr(sz); incr(r); w.b0 \leftarrow qi(so(str_pool[m])); w.b1 \leftarrow qi(so(str_pool[m + 1]));$
 $w.b2 \leftarrow qi(so(str_pool[m + 2])); w.b3 \leftarrow qi(so(str_pool[m + 3])); mem[r].qqqq \leftarrow w; m \leftarrow m + 4;$
 end;
 $w.b0 \leftarrow qi("_"); w.b1 \leftarrow qi("_"); w.b2 \leftarrow qi("_"); w.b3 \leftarrow qi("_");$
 if $l > m$ **then**
 begin $w.b0 \leftarrow qi(so(str_pool[m]));$
 if $l > m + 1$ **then**
 begin $w.b1 \leftarrow qi(so(str_pool[m + 1]));$
 if $l > m + 2$ **then**
 begin $w.b2 \leftarrow qi(so(str_pool[m + 2]));$
 if $l > m + 3$ **then** $w.b3 \leftarrow qi(so(str_pool[m + 3]));$
 end;
 end;
 end;
 $mem[r + 1].qqqq \leftarrow w;$
 if $str_pool[l] = nl$ **then** $incr(l);$
 end;
 $info(p) \leftarrow link(p); link(p) \leftarrow pseudo_files; pseudo_files \leftarrow p$

This code is used in section 1750.

1752. \langle Initiate input from new pseudo file 1752 $\rangle \equiv$
 $begin_file_reading; \{ \text{set up } cur_file \text{ and new level of input} \}$
 $line \leftarrow 0; limit \leftarrow start; loc \leftarrow limit + 1; \{ \text{force line read} \}$
if $tracing_scan_tokens > 0$ **then**
 begin if $term_offset > max_print_line - 3$ **then** $print_ln$
 else if $(term_offset > 0) \vee (file_offset > 0)$ **then** $print_char("_");$
 $name \leftarrow 19; print("_"); incr(open_parens); update_terminal;$
 end
else $name \leftarrow 18$

This code is used in section 1750.

1753. Here we read a line from the current pseudo file into *buffer*.

⟨Declare ε -TeX procedures for tracing and input 306⟩ +≡

```
function pseudo_input: boolean; { inputs the next line or returns false }
  var p: pointer; { current line from pseudo file }
      sz: integer; { size of node p }
      w: four_quarters; { four ASCII codes }
      r: pointer; { loop index }
  begin last  $\leftarrow$  first; { cf. Matthew 19:30 }
  p  $\leftarrow$  info(pseudo_files);
  if p = null then pseudo_input  $\leftarrow$  false
  else begin info(pseudo_files)  $\leftarrow$  link(p); sz  $\leftarrow$  ho(info(p));
    if  $4 * sz - 3 \geq \text{buf\_size} - \text{last}$  then ⟨Report overflow of the input buffer, and abort 35⟩;
    last  $\leftarrow$  first;
    for r  $\leftarrow$  p + 1 to p + sz - 1 do
      begin w  $\leftarrow$  mem[r].qqqq; buffer[last]  $\leftarrow$  w.b0; buffer[last + 1]  $\leftarrow$  w.b1; buffer[last + 2]  $\leftarrow$  w.b2;
      buffer[last + 3]  $\leftarrow$  w.b3; last  $\leftarrow$  last + 4;
      end;
    if last  $\geq$  max_buf_stack then max_buf_stack  $\leftarrow$  last + 1;
    while (last > first)  $\wedge$  (buffer[last - 1] = "□") do decr(last);
    free_node(p, sz); pseudo_input  $\leftarrow$  true;
  end;
end;
```

1754. When we are done with a pseudo file we ‘close’ it.

⟨Declare ε -TeX procedures for tracing and input 306⟩ +≡

```
procedure pseudo_close; { close the top level pseudo file }
  var p, q: pointer;
  begin p  $\leftarrow$  link(pseudo_files); q  $\leftarrow$  info(pseudo_files); free_avail(pseudo_files); pseudo_files  $\leftarrow$  p;
  while q  $\neq$  null do
    begin p  $\leftarrow$  q; q  $\leftarrow$  link(p); free_node(p, ho(info(p)));
    end;
  end;
```

1755. ⟨Dump the ε -TeX state 1651⟩ +≡

```
while pseudo_files  $\neq$  null do pseudo_close; { flush pseudo files }
```

1756. ⟨Generate all ε -TeX primitives 1646⟩ +≡

```
primitive("readline", read_to_cs, 1);
```

1757. ⟨Cases of *read* for *print_cmd_chr* 1757⟩ ≡

```
else print_esc("readline")
```

This code is used in section 288.

1758. \langle Handle `\readline` and `goto done 1758` $\rangle \equiv$

```

if j = 1 then
  begin while loc ≤ limit do { current line not yet finished }
    begin cur_chr ← buffer[loc]; incr(loc);
    if cur_chr = "␣" then cur_tok ← space_token else cur_tok ← cur_chr + other_token;
    store_new_token(cur_tok);
    end;
  goto done;
end

```

This code is used in section 509.

1759. Here we define the additional conditionals of ε -TeX as well as the `\unless` prefix.

```

define if_def_code = 17 { '\ifdefined' }
define if_cs_code = 18 { '\ifcsname' }
define if_font_char_code = 19 { '\iffontchar' }
define if_in_csname_code = 20 { '\ifincsname' }
define if_pdfabs_num_code = 22 { '\ifpdfabsnum' }
  { 21 = if_pdfprimitive }
define if_pdfabs_dim_code = 23 { '\ifpdfabsdim' }
 $\langle$  Generate all  $\varepsilon$ -TeX primitives 1646  $\rangle + \equiv$ 
primitive("unless", expand_after, 1);
primitive("ifdefined", if_test, if_def_code); primitive("ifcsname", if_test, if_cs_code);
primitive("iffontchar", if_test, if_font_char_code); primitive("ifincsname", if_test, if_in_csname_code);
primitive("ifpdfabsnum", if_test, if_pdfabs_num_code);
primitive("ifpdfabsdim", if_test, if_pdfabs_dim_code);

```

1760. \langle Cases of *expandafter* for *print_cmd_chr 1760* $\rangle \equiv$
`else print_esc("unless")`

This code is used in section 288.

1761. \langle Cases of *if_test* for *print_cmd_chr 1761* $\rangle \equiv$

```

if_def_code: print_esc("ifdefined");
if_cs_code: print_esc("ifcsname");
if_font_char_code: print_esc("iffontchar");
if_in_csname_code: print_esc("ifincsname");
if_pdfabs_num_code: print_esc("ifpdfabsnum");
if_pdfabs_dim_code: print_esc("ifpdfabsdim");

```

This code is used in section 514.

1762. The result of a boolean condition is reversed when the conditional is preceded by `\unless`.

\langle Negate a boolean conditional and `goto reswitch 1762` $\rangle \equiv$

```

begin get_token;
if (cur_cmd = if_test) ∧ (cur_chr ≠ if_case_code) then
  begin cur_chr ← cur_chr + unless_code; goto reswitch;
end;
print_err("You␣can't␣use␣"); print_esc("unless"); print("␣before␣");
print_cmd_chr(cur_cmd, cur_chr); print_char("␣");
help1("Continue,␣and␣I'll␣forget␣that␣it␣ever␣happened."); back_error;
end

```

This code is used in section 391.

1763. The conditional `\ifdefined` tests if a control sequence is defined.

We need to reset *scanner_status*, since `\outer` control sequences are allowed, but we might be scanning a macro definition or preamble.

⟨Cases for *conditional 1763*⟩ \equiv

```
if_def_code: begin save_scanner_status  $\leftarrow$  scanner_status; scanner_status  $\leftarrow$  normal; get_next;
  b  $\leftarrow$  (cur_cmd  $\neq$  undefined_cs); scanner_status  $\leftarrow$  save_scanner_status;
end;
```

See also sections 1764 and 1766.

This code is used in section 527.

1764. The conditional `\ifcsname` is equivalent to `{\expandafter }\expandafter \ifdefined \csname`, except that no new control sequence will be entered into the hash table (once all tokens preceding the mandatory `\endcsname` have been expanded).

⟨Cases for *conditional 1763*⟩ $+\equiv$

```
if_cs_code: begin n  $\leftarrow$  get_avail; p  $\leftarrow$  n; { head of the list of characters }
  e  $\leftarrow$  is_in_csname; is_in_csname  $\leftarrow$  true;
  repeat get_x_token;
    if cur_cs = 0 then store_new_token(cur_tok);
until cur_cs  $\neq$  0;
if cur_cmd  $\neq$  end_cs_name then ⟨Complain about missing \endcsname 399⟩;
⟨Look up the characters of list n in the hash table, and set cur_cs 1765⟩;
flush_list(n); b  $\leftarrow$  (eq_type(cur_cs)  $\neq$  undefined_cs); is_in_csname  $\leftarrow$  e;
end;
```

1765. ⟨Look up the characters of list *n* in the hash table, and set *cur_cs* 1765⟩ \equiv

```
m  $\leftarrow$  first; p  $\leftarrow$  link(n);
while p  $\neq$  null do
  begin if m  $\geq$  max_buf_stack then
    begin max_buf_stack  $\leftarrow$  m + 1;
    if max_buf_stack = buf_size then overflow("buffer_size", buf_size);
    end;
  buffer[m]  $\leftarrow$  info(p) mod '400; incr(m); p  $\leftarrow$  link(p);
end;
if m > first + 1 then cur_cs  $\leftarrow$  id_lookup(first, m - first) { no_new_control_sequence is true }
else if m = first then cur_cs  $\leftarrow$  null_cs { the list is empty }
  else cur_cs  $\leftarrow$  single_base + buffer[first] { the list has length one }
```

This code is used in section 1764.

1766. The conditional `\iffontchar` tests the existence of a character in a font.

```

⟨ Cases for conditional 1763 ⟩ +≡
if_in_csname_code: b ← is_in_csname;
if_pdfabs_dim_code, if_pdfabs_num_code: begin if this_if = if_pdfabs_num_code then
  scan_int else scan_normal_dimen;
  n ← cur_val;
  if n < 0 then negate(n);
  ⟨ Get the next non-blank non-call token 432 ⟩;
  if (cur_tok ≥ other_token + "<") ∧ (cur_tok ≤ other_token + ">") then r ← cur_tok - other_token
else begin print_err("Missing_ inserted_for_"); print_cmd_chr(if_test, this_if);
  help1("I_was expecting_to see '<', '=, or '>'. Didn't."); back_error; r ← "=";
end;
if this_if = if_pdfabs_num_code then scan_int else scan_normal_dimen;
if cur_val < 0 then negate(cur_val);
case r of
  "<": b ← (n < cur_val);
  "=": b ← (n = cur_val);
  ">": b ← (n > cur_val);
end;
end;
if_font_char_code: begin scan_font_ident; n ← cur_val; scan_char_num;
  if (font_bc[n] ≤ cur_val) ∧ (font_ec[n] ≥ cur_val) then b ← char_exists(char_info(n)(qi(cur_val)))
  else b ← false;
end;

```

1767. The *protected* feature of ε -TEX defines the `\protected` prefix command for macro definitions. Such macros are protected against expansions when lists of expanded tokens are built, e.g., for `\edef` or during `\write`.

```

⟨ Generate all  $\varepsilon$ -TEX primitives 1646 ⟩ +≡
primitive("protected", prefix, 8);

```

```

1768. ⟨ Cases of prefix for print_cmd_chr 1768 ⟩ ≡
else if chr_code = 8 then print_esc("protected")

```

This code is used in section 1385.

1769. The *get_x_or_protected* procedure is like *get_x_token* except that protected macros are not expanded.

```

⟨ Declare  $\varepsilon$ -TEX procedures for scanning 1679 ⟩ +≡
procedure get_x_or_protected; { sets cur_cmd, cur_chr, cur_tok, and expands non-protected macros }
  label exit;
  begin loop begin get_token;
    if cur_cmd ≤ max_command then return;
    if (cur_cmd ≥ call) ∧ (cur_cmd < end_template) then
      if info(link(cur_chr)) = protected_token then return;
    expand;
  end;
exit: end;

```


1770. A group entered (or a conditional started) in one file may end in a different file. Such slight anomalies, although perfectly legitimate, may cause errors that are difficult to locate. In order to be able to give a warning message when such anomalies occur, ε -TeX uses the *grp_stack* and *if_stack* arrays to record the initial *cur_boundary* and *cond_ptr* values for each input file.

⟨Global variables 13⟩ +≡

```
grp_stack: array [0 .. max_in_open] of save_pointer; { initial cur_boundary }
if_stack: array [0 .. max_in_open] of pointer; { initial cond_ptr }
```

1771. When a group ends that was apparently entered in a different input file, the *group_warning* procedure is invoked in order to update the *grp_stack*. If moreover `\tracingnesting` is positive we want to give a warning message. The situation is, however, somewhat complicated by two facts: (1) There may be *grp_stack* elements without a corresponding `\input` file or `\scantokens` pseudo file (e.g., error insertions from the terminal); and (2) the relevant information is recorded in the *name_field* of the *input_stack* only loosely synchronized with the *in_open* variable indexing *grp_stack*.

⟨Declare ε -TeX procedures for tracing and input 306⟩ +≡

procedure *group_warning*;

```
var i: 0 .. max_in_open; { index into grp_stack }
```

```
w: boolean; { do we need a warning? }
```

```
begin base_ptr  $\leftarrow$  input_ptr; input_stack[base_ptr]  $\leftarrow$  cur_input; { store current state }
```

```
i  $\leftarrow$  in_open; w  $\leftarrow$  false;
```

```
while (grp_stack[i] = cur_boundary)  $\wedge$  (i > 0) do
```

```
  begin ⟨Set variable w to indicate if this case should be reported 1772⟩;
```

```
  grp_stack[i]  $\leftarrow$  save_index(save_ptr); decr(i);
```

```
  end;
```

```
if w then
```

```
  begin print_nl("Warning: end of "); print_group(true); print(" of a different file"); print_ln;
```

```
  if tracing_nesting > 1 then show_context;
```

```
  if history = spotless then history  $\leftarrow$  warning_issued;
```

```
  end;
```

```
end;
```

1772. This code scans the input stack in order to determine the type of the current input file.

⟨Set variable *w* to indicate if this case should be reported 1772⟩ \equiv

```
if tracing_nesting > 0 then
```

```
  begin while (input_stack[base_ptr].state_field = token_list)  $\vee$  (input_stack[base_ptr].index_field > i) do  
    decr(base_ptr);
```

```
  if input_stack[base_ptr].name_field > 17 then w  $\leftarrow$  true;
```

```
  end
```

This code is used in sections 1771 and 1773.

1773. When a conditional ends that was apparently started in a different input file, the *if_warning* procedure is invoked in order to update the *if_stack*. If moreover `\tracingnesting` is positive we want to give a warning message (with the same complications as above).

(Declare ε -TEX procedures for tracing and input 306) +≡

```
procedure if_warning;
  var i: 0 .. max_in_open; { index into if_stack }
      w: boolean; { do we need a warning? }
  begin base_ptr  $\leftarrow$  input_ptr; input_stack[base_ptr]  $\leftarrow$  cur_input; { store current state }
  i  $\leftarrow$  in_open; w  $\leftarrow$  false;
  while if_stack[i] = cond_ptr do
    begin (Set variable w to indicate if this case should be reported 1772);
    if_stack[i]  $\leftarrow$  link(cond_ptr); decr(i);
    end;
  if w then
    begin print_nl("Warning: end of "); print_cmd_chr(if_test, cur_if); print_if_line(if_line);
    print(" of a different file"); print_ln;
    if tracing_nesting > 1 then show_context;
    if history = spotless then history  $\leftarrow$  warning_issued;
    end;
  end;
```

1774. Conversely, the *file_warning* procedure is invoked when a file ends and some groups entered or conditionals started while reading from that file are still incomplete.

(Declare ε -TEX procedures for tracing and input 306) +≡

```
procedure file_warning;
  var p: pointer; { saved value of save_ptr or cond_ptr }
      l: quarterword; { saved value of cur_level or if_limit }
      c: quarterword; { saved value of cur_group or cur_if }
      i: integer; { saved value of if_line }
  begin p  $\leftarrow$  save_ptr; l  $\leftarrow$  cur_level; c  $\leftarrow$  cur_group; save_ptr  $\leftarrow$  cur_boundary;
  while grp_stack[in_open]  $\neq$  save_ptr do
    begin decr(cur_level); print_nl("Warning: end of file when "); print_group(true);
    print(" is incomplete");
    cur_group  $\leftarrow$  save_level(save_ptr); save_ptr  $\leftarrow$  save_index(save_ptr)
    end;
  save_ptr  $\leftarrow$  p; cur_level  $\leftarrow$  l; cur_group  $\leftarrow$  c; { restore old values }
  p  $\leftarrow$  cond_ptr; l  $\leftarrow$  if_limit; c  $\leftarrow$  cur_if; i  $\leftarrow$  if_line;
  while if_stack[in_open]  $\neq$  cond_ptr do
    begin print_nl("Warning: end of file when "); print_cmd_chr(if_test, cur_if);
    if if_limit = fi_code then print_esc("else");
    print_if_line(if_line); print(" is incomplete");
    if_line  $\leftarrow$  if_line_field(cond_ptr); cur_if  $\leftarrow$  subtype(cond_ptr); if_limit  $\leftarrow$  type(cond_ptr);
    cond_ptr  $\leftarrow$  link(cond_ptr);
    end;
  cond_ptr  $\leftarrow$  p; if_limit  $\leftarrow$  l; cur_if  $\leftarrow$  c; if_line  $\leftarrow$  i; { restore old values }
  print_ln;
  if tracing_nesting > 1 then show_context;
  if history = spotless then history  $\leftarrow$  warning_issued;
  end;
```

1775. Here are the additional ε -TeX primitives for expressions.

```

⟨Generate all  $\varepsilon$ -TeX primitives 1646⟩ +≡
  primitive("numexpr", last_item, eTeX_expr - int_val + int_val);
  primitive("dimexpr", last_item, eTeX_expr - int_val + dimen_val);
  primitive("glueexpr", last_item, eTeX_expr - int_val + glue_val);
  primitive("muexpr", last_item, eTeX_expr - int_val + mu_val);

```

1776. ⟨Cases of *last_item* for *print_cmd_chr* 1647⟩ +≡

```

eTeX_expr - int_val + int_val: print_esc("numexpr");
eTeX_expr - int_val + dimen_val: print_esc("dimexpr");
eTeX_expr - int_val + glue_val: print_esc("glueexpr");
eTeX_expr - int_val + mu_val: print_esc("muexpr");

```

1777. This code for reducing *cur_val_level* and/or negating the result is similar to the one for all the other cases of *scan_something_internal*, with the difference that *scan_expr* has already increased the reference count of a glue specification.

```

⟨Process an expression and return 1777⟩ ≡
  begin if m < eTeX_mu then
    begin case m of
      ⟨Cases for fetching a glue value 1804⟩
    end; { there are no other cases }
    cur_val_level ← glue_val;
  end
  else if m < eTeX_expr then
    begin case m of
      ⟨Cases for fetching a mu value 1805⟩
    end; { there are no other cases }
    cur_val_level ← mu_val;
  end
  else begin cur_val_level ← m - eTeX_expr + int_val; scan_expr;
  end;
  while cur_val_level > level do
    begin if cur_val_level = glue_val then
      begin m ← cur_val; cur_val ← width(m); delete_glue_ref(m);
      end
    else if cur_val_level = mu_val then mu_error;
    decr(cur_val_level);
  end;
  if negative then
    if cur_val_level ≥ glue_val then
      begin m ← cur_val; cur_val ← new_spec(m); delete_glue_ref(m);
      ⟨Negate all three glue components of cur_val 457⟩;
      end
    else negate(cur_val);
  end;
  return;
end

```

This code is used in section 450.

1778. ⟨Declare ε -TeX procedures for scanning 1679⟩ +≡

```

procedure scan_expr; forward;

```

1779. The *scan_expr* procedure scans and evaluates an expression.

\langle Declare procedures needed for expressions 1779 $\rangle \equiv$

\langle Declare subprocedures for *scan_expr* 1790 \rangle

procedure *scan_expr*; { scans and evaluates an expression }

label *restart, continue, found*;

var *a, b*: *boolean*; { saved values of *arith_error* }

l: *small_number*; { type of expression }

r: *small_number*; { state of expression so far }

s: *small_number*; { state of term so far }

o: *small_number*; { next operation or type of next factor }

e: *integer*; { expression so far }

t: *integer*; { term so far }

f: *integer*; { current factor }

n: *integer*; { numerator of combined multiplication and division }

p: *pointer*; { top of expression stack }

q: *pointer*; { for stack manipulations }

begin *l* \leftarrow *cur_val_level*; *a* \leftarrow *arith_error*; *b* \leftarrow *false*; *p* \leftarrow *null*; *incr*(*expand_depth_count*);

if *expand_depth_count* \geq *expand_depth* **then** *overflow*("expansion_depth", *expand_depth*);

\langle Scan and evaluate an expression *e* of type *l* 1780 \rangle ;

decr(*expand_depth_count*);

if *b* **then**

begin *print_err*("Arithmetic_overflow"); *help2*("I can't evaluate this expression,")

 ("since the result is out of range."); *error*;

if *l* \geq *glue_val* **then**

begin *delete_glue_ref*(*e*); *e* \leftarrow *zero_glue*; *add_glue_ref*(*e*);

end

else *e* \leftarrow 0;

end;

arith_error \leftarrow *a*; *cur_val* \leftarrow *e*; *cur_val_level* \leftarrow *l*;

end;

See also section 1784.

This code is used in section 487.

1780. Evaluating an expression is a recursive process: When the left parenthesis of a subexpression is scanned we descend to the next level of recursion; the previous level is resumed with the matching right parenthesis.

```

define expr_none = 0 { ( seen, or ( <expr> ) seen }
define expr_add = 1 { ( <expr> + seen }
define expr_sub = 2 { ( <expr> - seen }
define expr_mult = 3 { <term> * seen }
define expr_div = 4 { <term> / seen }
define expr_scale = 5 { <term> * <factor> / seen }

<Scan and evaluate an expression e of type l 1780> ≡
restart: r ← expr_none; e ← 0; s ← expr_none; t ← 0; n ← 0;
continue: if s = expr_none then o ← l else o ← int_val;
  <Scan a factor f of type o or start a subexpression 1782>;
found: <Scan the next operator and set o 1781>;
  arith_error ← b; <Make sure that f is in the proper range 1787>;
case s of
  <Cases for evaluation of the current term 1788>
end; { there are no other cases }
if o > expr_sub then s ← o else <Evaluate the current expression 1789>;
b ← arith_error;
if o ≠ expr_none then goto continue;
if p ≠ null then <Pop the expression stack and goto found 1786>

```

This code is used in section 1779.

```

1781. <Scan the next operator and set o 1781> ≡
  <Get the next non-blank non-call token 432>;
if cur_tok = other_token + "+" then o ← expr_add
else if cur_tok = other_token + "-" then o ← expr_sub
  else if cur_tok = other_token + "*" then o ← expr_mult
  else if cur_tok = other_token + "/" then o ← expr_div
  else begin o ← expr_none;
    if p = null then
      begin if cur_cmd ≠ relax then back_input;
      end
    else if cur_tok ≠ other_token + ")" then
      begin print_err("Missing_ inserted_for_expression");
      help1("I_was expecting to see `+', `-', `*', `/', or `')'. Didn't."); back_error;
      end;
    end

```

This code is used in section 1780.

```

1782. <Scan a factor f of type o or start a subexpression 1782> ≡
  <Get the next non-blank non-call token 432>;
if cur_tok = other_token + "(" then <Push the expression stack and goto restart 1785>;
  back_input;
if o = int_val then scan_int
else if o = dimen_val then scan_normal_dimen
  else if o = glue_val then scan_normal_glue
    else scan_mu_glue;
  f ← cur_val

```

This code is used in section 1780.

1783. \langle Declare ε -TeX procedures for scanning 1679 $\rangle + \equiv$

procedure *scan_normal_glue*; *forward*;

procedure *scan_mu_glue*; *forward*;

1784. Here we declare two trivial procedures in order to avoid mutually recursive procedures with parameters.

\langle Declare procedures needed for expressions 1779 $\rangle + \equiv$

procedure *scan_normal_glue*;

begin *scan_glue*(*glue_val*);

end;

procedure *scan_mu_glue*;

begin *scan_glue*(*mu_val*);

end;

1785. Parenthesized subexpressions can be inside expressions, and this nesting has a stack. Seven local variables represent the top of the expression stack: *p* points to pushed-down entries, if any; *l* specifies the type of expression currently being evaluated; *e* is the expression so far and *r* is the state of its evaluation; *t* is the term so far and *s* is the state of its evaluation; finally *n* is the numerator for a combined multiplication and division, if any.

define *expr_node_size* = 4 { number of words in stack entry for subexpressions }

define *expr_e_field*(#) \equiv *mem*[# + 1].*int* { saved expression so far }

define *expr_t_field*(#) \equiv *mem*[# + 2].*int* { saved term so far }

define *expr_n_field*(#) \equiv *mem*[# + 3].*int* { saved numerator }

\langle Push the expression stack and **goto** *restart* 1785 $\rangle \equiv$

begin *q* \leftarrow *get_node*(*expr_node_size*); *link*(*q*) \leftarrow *p*; *type*(*q*) \leftarrow *l*; *subtype*(*q*) \leftarrow $4 * s + r$;

expr_e_field(*q*) \leftarrow *e*; *expr_t_field*(*q*) \leftarrow *t*; *expr_n_field*(*q*) \leftarrow *n*; *p* \leftarrow *q*; *l* \leftarrow *o*; **goto** *restart*;

end

This code is used in section 1782.

1786. \langle Pop the expression stack and **goto** *found* 1786 $\rangle \equiv$

begin *f* \leftarrow *e*; *q* \leftarrow *p*; *e* \leftarrow *expr_e_field*(*q*); *t* \leftarrow *expr_t_field*(*q*); *n* \leftarrow *expr_n_field*(*q*); *s* \leftarrow *subtype*(*q*) **div** 4;

r \leftarrow *subtype*(*q*) **mod** 4; *l* \leftarrow *type*(*q*); *p* \leftarrow *link*(*q*); *free_node*(*q*, *expr_node_size*); **goto** *found*;

end

This code is used in section 1780.

1787. We want to make sure that each term and (intermediate) result is in the proper range. Integer values must not exceed *infinity* ($2^{31} - 1$) in absolute value, dimensions must not exceed *max_dimen* ($2^{30} - 1$). We avoid the absolute value of an integer, because this might fail for the value -2^{31} using 32-bit arithmetic.

```

define num_error(#)  $\equiv$  { clear a number or dimension and set arith_error }
    begin arith_error  $\leftarrow$  true; #  $\leftarrow$  0;
    end
define glue_error(#)  $\equiv$  { clear a glue spec and set arith_error }
    begin arith_error  $\leftarrow$  true; delete_glue_ref(#); #  $\leftarrow$  new_spec(zero_glue);
    end

⟨ Make sure that f is in the proper range 1787 ⟩  $\equiv$ 
if (l = int_val)  $\vee$  (s > expr_sub) then
    begin if (f > infinity)  $\vee$  (f <  $-infinity$ ) then num_error(f);
    end
else if l = dimen_val then
    begin if abs(f) > max_dimen then num_error(f);
    end
    else begin if (abs(width(f)) > max_dimen)  $\vee$  (abs(stretch(f)) > max_dimen)  $\vee$ 
        (abs(shrink(f)) > max_dimen) then glue_error(f);
    end

```

This code is used in section 1780.

1788. Applying the factor *f* to the partial term *t* (with the operator *s*) is delayed until the next operator *o* has been scanned. Here we handle the first factor of a partial term. A glue spec has to be copied unless the next operator is a right parenthesis; this allows us later on to simply modify the glue components.

```

define normalize_glue(#)  $\equiv$ 
    if stretch(#) = 0 then stretch_order(#)  $\leftarrow$  normal;
    if shrink(#) = 0 then shrink_order(#)  $\leftarrow$  normal

⟨ Cases for evaluation of the current term 1788 ⟩  $\equiv$ 
expr_none: if (l  $\geq$  glue_val)  $\wedge$  (o  $\neq$  expr_none) then
    begin t  $\leftarrow$  new_spec(f); delete_glue_ref(f); normalize_glue(t);
    end
else t  $\leftarrow$  f;

```

See also sections 1792, 1793, and 1795.

This code is used in section 1780.

1789. When a term *t* has been completed it is copied to, added to, or subtracted from the expression *e*.

```

define expr_add_sub(#)  $\equiv$  add_or_sub(#, r = expr_sub)
define expr_a(#)  $\equiv$  expr_add_sub(#, max_dimen)

⟨ Evaluate the current expression 1789 ⟩  $\equiv$ 
begin s  $\leftarrow$  expr_none;
if r = expr_none then e  $\leftarrow$  t
else if l = int_val then e  $\leftarrow$  expr_add_sub(e, t, infinity)
    else if l = dimen_val then e  $\leftarrow$  expr_a(e, t)
    else ⟨ Compute the sum or difference of two glue specs 1791 ⟩;
    r  $\leftarrow$  o;
end

```

This code is used in section 1780.

1790. The function $add_or_sub(x, y, max_answer, negative)$ computes the sum (for $negative = false$) or difference (for $negative = true$) of x and y , provided the absolute value of the result does not exceed max_answer .

\langle Declare subprocedures for $scan_expr$ 1790 $\rangle \equiv$

```
function  $add\_or\_sub(x, y, max\_answer : integer; negative : boolean) : integer;$ 
  var  $a : integer;$  { the answer }
  begin if  $negative$  then  $negate(y);$ 
  if  $x \geq 0$  then
    if  $y \leq max\_answer - x$  then  $a \leftarrow x + y$  else  $num\_error(a)$ 
  else if  $y \geq -max\_answer - x$  then  $a \leftarrow x + y$  else  $num\_error(a);$ 
   $add\_or\_sub \leftarrow a;$ 
  end;
```

See also sections 1794 and 1796.

This code is used in section 1779.

1791. We know that $stretch_order(e) > normal$ implies $stretch(e) \neq 0$ and $shrink_order(e) > normal$ implies $shrink(e) \neq 0$.

\langle Compute the sum or difference of two glue specs 1791 $\rangle \equiv$

```
begin  $width(e) \leftarrow expr\_a(width(e), width(t));$ 
if  $stretch\_order(e) = stretch\_order(t)$  then  $stretch(e) \leftarrow expr\_a(stretch(e), stretch(t))$ 
else if  $(stretch\_order(e) < stretch\_order(t)) \wedge (stretch(t) \neq 0)$  then
  begin  $stretch(e) \leftarrow stretch(t); stretch\_order(e) \leftarrow stretch\_order(t);$ 
  end;
if  $shrink\_order(e) = shrink\_order(t)$  then  $shrink(e) \leftarrow expr\_a(shrink(e), shrink(t))$ 
else if  $(shrink\_order(e) < shrink\_order(t)) \wedge (shrink(t) \neq 0)$  then
  begin  $shrink(e) \leftarrow shrink(t); shrink\_order(e) \leftarrow shrink\_order(t);$ 
  end;
 $delete\_glue\_ref(t); normalize\_glue(e);$ 
end
```

This code is used in section 1789.

1792. If a multiplication is followed by a division, the two operations are combined into a ‘scaling’ operation. Otherwise the term t is multiplied by the factor f .

```
define  $expr\_m(\#) \equiv \# \leftarrow nx\_plus\_y(\#, f, 0)$ 
```

\langle Cases for evaluation of the current term 1788 $\rangle + \equiv$

```
 $expr\_mult:$  if  $o = expr\_div$  then
  begin  $n \leftarrow f; o \leftarrow expr\_scale;$ 
  end
else if  $l = int\_val$  then  $t \leftarrow mult\_integers(t, f)$ 
else if  $l = dimen\_val$  then  $expr\_m(t)$ 
  else begin  $expr\_m(width(t)); expr\_m(stretch(t)); expr\_m(shrink(t));$ 
  end;
```

1793. Here we divide the term t by the factor f .

```
define  $expr\_d(\#) \equiv \# \leftarrow quotient(\#, f)$ 
```

\langle Cases for evaluation of the current term 1788 $\rangle + \equiv$

```
 $expr\_div:$  if  $l < glue\_val$  then  $expr\_d(t)$ 
else begin  $expr\_d(width(t)); expr\_d(stretch(t)); expr\_d(shrink(t));$ 
end;
```


1794. The function *quotient*(n, d) computes the rounded quotient $q = \lfloor n/d + \frac{1}{2} \rfloor$, when n and d are positive.

\langle Declare subprocedures for *scan_expr* 1790 $\rangle + \equiv$

```
function quotient( $n, d : integer$ ): integer;
  var negative: boolean; { should the answer be negated? }
    a: integer; { the answer }
  begin if  $d = 0$  then num_error( $a$ )
  else begin if  $d > 0$  then negative  $\leftarrow$  false
    else begin negate( $d$ ); negative  $\leftarrow$  true;
    end;
    if  $n < 0$  then
      begin negate( $n$ ); negative  $\leftarrow$   $\neg$ negative;
      end;
     $a \leftarrow n \text{ div } d$ ;  $n \leftarrow n - a * d$ ;  $d \leftarrow n - d$ ; { avoid certain compiler optimizations! }
    if  $d + n \geq 0$  then incr( $a$ );
    if negative then negate( $a$ );
    end;
  quotient  $\leftarrow$   $a$ ;
end;
```

1795. Here the term t is multiplied by the quotient n/f .

define *expr_s*($\#$) $\equiv \# \leftarrow \text{fract}(\#, n, f, \text{max_dimen})$

\langle Cases for evaluation of the current term 1788 $\rangle + \equiv$

```
expr_scale: if  $l = \text{int\_val}$  then  $t \leftarrow \text{fract}(t, n, f, \text{infinity})$ 
else if  $l = \text{dimen\_val}$  then expr_s( $t$ )
  else begin expr_s(width( $t$ )); expr_s(stretch( $t$ )); expr_s(shrink( $t$ ));
  end;
```

1796. Finally, the function $\text{fract}(x, n, d, \text{max_answer})$ computes the integer $q = \lfloor xn/d + \frac{1}{2} \rfloor$, when x , n , and d are positive and the result does not exceed max_answer . We can't use floating point arithmetic since the routine must produce identical results in all cases; and it would be too dangerous to multiply by n and then divide by d , in separate operations, since overflow might well occur. Hence this subroutine simulates double precision arithmetic, somewhat analogous to METAFONT's *make_fraction* and *take_fraction* routines.

```

define too_big = 88 { go here when the result is too big }
⟨ Declare subprocedures for scan_expr 1790 ⟩ +≡
function fract( $x, n, d, \text{max\_answer} : \text{integer}$ ): integer;
  label found, found1, too_big, done;
  var negative: boolean; { should the answer be negated? }
    a: integer; { the answer }
    f: integer; { a proper fraction }
    h: integer; { smallest integer such that  $2 * h \geq d$  }
    r: integer; { intermediate remainder }
    t: integer; { temp variable }
  begin if  $d = 0$  then goto too_big;
   $a \leftarrow 0$ ;
  if  $d > 0$  then negative  $\leftarrow$  false
  else begin negate( $d$ ); negative  $\leftarrow$  true;
    end;
  if  $x < 0$  then
    begin negate( $x$ ); negative  $\leftarrow$   $\neg$ negative;
    end
  else if  $x = 0$  then goto done;
  if  $n < 0$  then
    begin negate( $n$ ); negative  $\leftarrow$   $\neg$ negative;
    end;
   $t \leftarrow n \text{ div } d$ ;
  if  $t > \text{max\_answer} \text{ div } x$  then goto too_big;
   $a \leftarrow t * x$ ;  $n \leftarrow n - t * d$ ;
  if  $n = 0$  then goto found;
   $t \leftarrow x \text{ div } d$ ;
  if  $t > (\text{max\_answer} - a) \text{ div } n$  then goto too_big;
   $a \leftarrow a + t * n$ ;  $x \leftarrow x - t * d$ ;
  if  $x = 0$  then goto found;
  if  $x < n$  then
    begin  $t \leftarrow x$ ;  $x \leftarrow n$ ;  $n \leftarrow t$ ;
    end; { now  $0 < n \leq x < d$  }
  ⟨ Compute  $f = \lfloor xn/d + \frac{1}{2} \rfloor$  1797 ⟩
  if  $f > (\text{max\_answer} - a)$  then goto too_big;
   $a \leftarrow a + f$ ;
found: if negative then negate( $a$ );
  goto done;
too_big: num_error( $a$ );
done: fract  $\leftarrow a$ ;
  end;

```

1797. The loop here preserves the following invariant relations between f , x , n , and r : (i) $f + \lfloor (xn + (r + d))/d \rfloor = \lfloor x_0 n_0 / d + \frac{1}{2} \rfloor$; (ii) $-d \leq r < 0 < n \leq x < d$, where x_0 , n_0 are the original values of x and n .

Notice that the computation specifies $(x - d) + x$ instead of $(x + x) - d$, because the latter could overflow.

```

⟨ Compute  $f = \lfloor xn/d + \frac{1}{2} \rfloor$  1797 ⟩ ≡
   $f \leftarrow 0$ ;  $r \leftarrow (d \text{ div } 2) - d$ ;  $h \leftarrow -r$ ;
  loop begin if  $\text{odd}(n)$  then
    begin  $r \leftarrow r + x$ ;
    if  $r \geq 0$  then
      begin  $r \leftarrow r - d$ ;  $\text{incr}(f)$ ;
      end;
    end;
     $n \leftarrow n \text{ div } 2$ ;
    if  $n = 0$  then goto found1;
    if  $x < h$  then  $x \leftarrow x + x$ 
  else begin  $t \leftarrow x - d$ ;  $x \leftarrow t + x$ ;  $f \leftarrow f + n$ ;
    if  $x < n$  then
      begin if  $x = 0$  then goto found1;
         $t \leftarrow x$ ;  $x \leftarrow n$ ;  $n \leftarrow t$ ;
      end;
    end;
  end;
found1:

```

This code is used in section 1796.

1798. The `\gluestretch`, `\glueshrink`, `\gluestretchorder`, and `\glueshrinkorder` commands return the stretch and shrink components and their orders of “infinity” of a glue specification.

```

define glue_stretch_order_code = eTeX_int + 6 { code for \gluestretchorder }
define glue_shrink_order_code = eTeX_int + 7 { code for \glueshrinkorder }
define glue_stretch_code = eTeX_dim + 7 { code for \gluestretch }
define glue_shrink_code = eTeX_dim + 8 { code for \glueshrink }

⟨ Generate all  $\varepsilon$ -TeX primitives 1646 ⟩ +=
  primitive("gluestretchorder", last_item, glue_stretch_order_code);
  primitive("glueshrinkorder", last_item, glue_shrink_order_code);
  primitive("gluestretch", last_item, glue_stretch_code);
  primitive("glueshrink", last_item, glue_shrink_code);

```

1799. ⟨ Cases of *last_item* for *print_cmd_chr* 1647 ⟩ +=
 $\text{glue_stretch_order_code}$: $\text{print_esc}(\text{"gluestretchorder"})$;
 $\text{glue_shrink_order_code}$: $\text{print_esc}(\text{"glueshrinkorder"})$;
 glue_stretch_code : $\text{print_esc}(\text{"gluestretch"})$;
 glue_shrink_code : $\text{print_esc}(\text{"glueshrink"})$;

1800. ⟨ Cases for fetching an integer value 1648 ⟩ +=
 $\text{glue_stretch_order_code}$, $\text{glue_shrink_order_code}$: **begin** scan_normal_glue ; $q \leftarrow \text{cur_val}$;
 if $m = \text{glue_stretch_order_code}$ **then** $\text{cur_val} \leftarrow \text{stretch_order}(q)$
 else $\text{cur_val} \leftarrow \text{shrink_order}(q)$;
 $\text{delete_glue_ref}(q)$;
end;

1801. \langle Cases for fetching a dimension value 1668 $\rangle + \equiv$
`glue_stretch_code, glue_shrink_code: begin scan_normal_glue; q \leftarrow cur_val;`
`if m = glue_stretch_code then cur_val \leftarrow stretch(q)`
`else cur_val \leftarrow shrink(q);`
`delete_glue_ref(q);`
`end;`

1802. The `\mutoglu` and `\gluetomu` commands convert “math” glue into normal glue and vice versa; they allow to manipulate math glue with `\gluestretch` etc.

```
define mu_to_glue_code = eTeX_glue {code for \mutoglu}
define glue_to_mu_code = eTeX_mu {code for \gluetomu}
 $\langle$ Generate all  $\varepsilon$ -TeX primitives 1646  $\rangle + \equiv$ 
primitive("mutoglu", last_item, mu_to_glue_code); primitive("gluetomu", last_item, glue_to_mu_code);
```

1803. \langle Cases of *last_item* for *print_cmd_chr* 1647 $\rangle + \equiv$
`mu_to_glue_code: print_esc("mutoglu");`
`glue_to_mu_code: print_esc("gluetomu");`

1804. \langle Cases for fetching a glue value 1804 $\rangle \equiv$
`mu_to_glue_code: scan_mu_glue;`
This code is used in section 1777.

1805. \langle Cases for fetching a mu value 1805 $\rangle \equiv$
`glue_to_mu_code: scan_normal_glue;`
This code is used in section 1777.

1806. ε -TeX (in extended mode) supports 32768 (i.e., 2^{15}) count, dimen, skip, muskip, box, and token registers. As in TeX the first 256 registers of each kind are realized as arrays in the table of equivalents; the additional registers are realized as tree structures built from variable-size nodes with individual registers existing only when needed. Default values are used for nonexistent registers: zero for count and dimen values, *zero_glue* for glue (skip and muskip) values, void for boxes, and *null* for token lists (and current marks discussed below).

Similarly there are 32768 mark classes; the command `\marks n` creates a mark node for a given mark class $0 \leq n \leq 32767$ (where `\marks0` is synonymous to `\mark`). The page builder (actually the *fire_up* routine) and the *vsplit* routine maintain the current values of *top_mark*, *first_mark*, *bot_mark*, *split_first_mark*, and *split_bot_mark* for each mark class. They are accessed as `\topmarks n` etc., and `\topmarks0` is again synonymous to `\topmark`. As in TeX the five current marks for mark class zero are realized as *cur_mark* array. The additional current marks are again realized as tree structure with individual mark classes existing only when needed.

```
 $\langle$ Generate all  $\varepsilon$ -TeX primitives 1646  $\rangle + \equiv$ 
primitive("marks", mark, marks_code);
primitive("topmarks", top_bot_mark, top_mark_code + marks_code);
primitive("firstmarks", top_bot_mark, first_mark_code + marks_code);
primitive("botmarks", top_bot_mark, bot_mark_code + marks_code);
primitive("splitfirstmarks", top_bot_mark, split_first_mark_code + marks_code);
primitive("splitbotmarks", top_bot_mark, split_bot_mark_code + marks_code);
```

1807. The *scan_register_num* procedure scans a register number that must not exceed 255 in compatibility mode resp. 32767 in extended mode.

```
 $\langle$ Declare  $\varepsilon$ -TeX procedures for expanding 1749  $\rangle + \equiv$ 
procedure scan_register_num; forward;
```

1808. \langle Declare procedures that scan restricted classes of integers 459 $\rangle + \equiv$

```
procedure scan_register_num;  
  begin scan_int;  
  if (cur_val < 0)  $\vee$  (cur_val > max_reg_num) then  
    begin print_err("Bad_register_code");  
      help2(max_reg_help_line)("I_changed_this_one_to_zero."); int_error(cur_val); cur_val  $\leftarrow$  0;  
    end;  
  end;
```

1809. \langle Initialize variables for ε -TeX compatibility mode 1809 $\rangle \equiv$

```
max_reg_num  $\leftarrow$  255; max_reg_help_line  $\leftarrow$  "A_register_number_must_be_between_0_and_255.";
```

This code is used in sections 1650 and 1652.

1810. \langle Initialize variables for ε -TeX extended mode 1810 $\rangle \equiv$

```
max_reg_num  $\leftarrow$  32767; max_reg_help_line  $\leftarrow$  "A_register_number_must_be_between_0_and_32767.";
```

This code is used in sections 1645 and 1652.

1811. \langle Global variables 13 $\rangle + \equiv$

```
max_reg_num: halfword; { largest allowed register number }  
max_reg_help_line: str_number; { first line of help message }
```

1812. There are seven almost identical doubly linked trees, one for the sparse array of the up to 32512 additional registers of each kind and one for the sparse array of the up to 32767 additional mark classes. The root of each such tree, if it exists, is an index node containing 16 pointers to subtrees for 4096 consecutive array elements. Similar index nodes are the starting points for all nonempty subtrees for 4096, 256, and 16 consecutive array elements. These four levels of index nodes are followed by a fifth level with nodes for the individual array elements.

Each index node is nine words long. The pointers to the 16 possible subtrees or are kept in the *info* and *link* fields of the last eight words. (It would be both elegant and efficient to declare them as array, unfortunately Pascal doesn't allow this.)

The fields in the first word of each index node and in the nodes for the array elements are closely related. The *link* field points to the next lower index node and the *sa_index* field contains four bits (one hexadecimal digit) of the register number or mark class. For the lowest index node the *link* field is *null* and the *sa_index* field indicates the type of quantity (*int_val*, *dimen_val*, *glue_val*, *mu_val*, *box_val*, *tok_val*, or *mark_val*). The *sa_used* field in the index nodes counts how many of the 16 pointers are non-null.

The *sa_index* field in the nodes for array elements contains the four bits plus 16 times the type. Therefore such a node represents a count or dimen register if and only if $sa_index < dimen_val_limit$; it represents a skip or muskip register if and only if $dimen_val_limit \leq sa_index < mu_val_limit$; it represents a box register if and only if $mu_val_limit \leq sa_index < box_val_limit$; it represents a token list register if and only if $box_val_limit \leq sa_index < tok_val_limit$; finally it represents a mark class if and only if $tok_val_limit \leq sa_index$.

The *new_index* procedure creates an index node (returned in *cur_ptr*) having given contents of the *sa_index* and *link* fields.

```

define box_val  $\equiv$  4 { the additional box registers }
define mark_val  $\equiv$  6 { the additional mark classes }
define dimen_val_limit = "20 {  $2^4 \cdot (dimen\_val + 1)$  }
define mu_val_limit = "40 {  $2^4 \cdot (mu\_val + 1)$  }
define box_val_limit = "50 {  $2^4 \cdot (box\_val + 1)$  }
define tok_val_limit = "60 {  $2^4 \cdot (tok\_val + 1)$  }

define index_node_size = 9 { size of an index node }
define sa_index  $\equiv$  type { a four-bit address or a type or both }
define sa_used  $\equiv$  subtype { count of non-null pointers }

⟨ Declare  $\varepsilon$ -TeX procedures for expanding 1749 ⟩  $\equiv$ 
procedure new_index(i : quarterword; q : pointer);
  var k : small_number; { loop index }
  begin cur_ptr  $\leftarrow$  get_node(index_node_size); sa_index(cur_ptr)  $\leftarrow$  i; sa_used(cur_ptr)  $\leftarrow$  0;
  link(cur_ptr)  $\leftarrow$  q;
  for k  $\leftarrow$  1 to index_node_size - 1 do { clear all 16 pointers }
    mem[cur_ptr + k]  $\leftarrow$  sa_null;
  end;

```

1813. The roots of the seven trees for the additional registers and mark classes are kept in the *sa_root* array. The first six locations must be dumped and undumped; the last one is also known as *sa_mark*.

```

define sa_mark  $\equiv$  sa_root[mark_val] { root for mark classes }

⟨ Global variables 13 ⟩  $\equiv$ 
sa_root : array [int_val .. mark_val] of pointer; { roots of sparse arrays }
cur_ptr : pointer; { value returned by new_index and find_sa_element }
sa_null : memory_word; { two null pointers }

```

1814. ⟨ Set initial values of key variables 21 ⟩ \equiv
sa_mark \leftarrow *null*; *sa_null.hh.lh* \leftarrow *null*; *sa_null.hh.rh* \leftarrow *null*;

1815. \langle Initialize table entries (done by INITEX only) 182 $\rangle + \equiv$
 for $i \leftarrow int_val$ **to** tok_val **do** $sa_root[i] \leftarrow null$;

1816. Given a type t and a sixteen-bit number n , the *find_sa_element* procedure returns (in *cur_ptr*) a pointer to the node for the corresponding array element, or *null* when no such element exists. The third parameter w is set *true* if the element must exist, e.g., because it is about to be modified. The procedure has two main branches: one follows the existing tree structure, the other (only used when w is *true*) creates the missing nodes.

We use macros to extract the four-bit pieces from a sixteen-bit register number or mark class and to fetch or store one of the 16 pointers from an index node.

```

define if_cur_ptr_is_null_then_return_or_goto(#)  $\equiv$  { some tree element is missing }
begin if cur_ptr = null then
  if  $w$  then goto # else return;
end

define hex_dig1(#)  $\equiv$  # div 4096 { the fourth lowest hexadecimal digit }
define hex_dig2(#)  $\equiv$  (# div 256) mod 16 { the third lowest hexadecimal digit }
define hex_dig3(#)  $\equiv$  (# div 16) mod 16 { the second lowest hexadecimal digit }
define hex_dig4(#)  $\equiv$  # mod 16 { the lowest hexadecimal digit }

define get_sa_ptr  $\equiv$ 
  if odd( $i$ ) then cur_ptr  $\leftarrow$  link( $q + (i \text{ div } 2) + 1$ )
  else cur_ptr  $\leftarrow$  info( $q + (i \text{ div } 2) + 1$ )
  { set cur_ptr to the pointer indexed by  $i$  from index node  $q$  }

define put_sa_ptr(#)  $\equiv$ 
  if odd( $i$ ) then link( $q + (i \text{ div } 2) + 1$ )  $\leftarrow$  #
  else info( $q + (i \text{ div } 2) + 1$ )  $\leftarrow$  # { store the pointer indexed by  $i$  in index node  $q$  }

define add_sa_ptr  $\equiv$ 
  begin put_sa_ptr(cur_ptr); incr(sa_used( $q$ ));
  end { add cur_ptr as the pointer indexed by  $i$  in index node  $q$  }

define delete_sa_ptr  $\equiv$ 
  begin put_sa_ptr(null); decr(sa_used( $q$ ));
  end { delete the pointer indexed by  $i$  in index node  $q$  }

(Declare  $\varepsilon$ -TeX procedures for expanding 1749)  $\equiv$ 
procedure find_sa_element( $t$  : small_number;  $n$  : halfword;  $w$  : boolean);
  { sets cur_val to sparse array element location or null }
  label not_found, not_found1, not_found2, not_found3, not_found4, exit;
  var  $q$ : pointer; { for list manipulations }
   $i$ : small_number; { a four bit index }
  begin cur_ptr  $\leftarrow$  sa_root[ $t$ ]; if_cur_ptr_is_null_then_return_or_goto(not_found);
   $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig1( $n$ ); get_sa_ptr; if_cur_ptr_is_null_then_return_or_goto(not_found1);
   $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig2( $n$ ); get_sa_ptr; if_cur_ptr_is_null_then_return_or_goto(not_found2);
   $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig3( $n$ ); get_sa_ptr; if_cur_ptr_is_null_then_return_or_goto(not_found3);
   $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig4( $n$ ); get_sa_ptr;
  if (cur_ptr = null)  $\wedge w$  then goto not_found4;
  return;

not_found: new_index( $t$ , null); { create first level index node }
  sa_root[ $t$ ]  $\leftarrow$  cur_ptr;  $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig1( $n$ );
not_found1: new_index( $i$ ,  $q$ ); { create second level index node }
  add_sa_ptr;  $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig2( $n$ );
not_found2: new_index( $i$ ,  $q$ ); { create third level index node }
  add_sa_ptr;  $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig3( $n$ );
not_found3: new_index( $i$ ,  $q$ ); { create fourth level index node }
  add_sa_ptr;  $q \leftarrow$  cur_ptr;  $i \leftarrow$  hex_dig4( $n$ );
not_found4: (Create a new array element of type  $t$  with index  $i$  1817);
  link(cur_ptr)  $\leftarrow$   $q$ ; add_sa_ptr;

```


exit: **end**;

1817. The array elements for registers are subject to grouping and have an *sa_lev* field (quite analogous to *eq_level*) instead of *sa_used*. Since saved values as well as shorthand definitions (created by e.g., `\countdef`) refer to the location of the respective array element, we need a reference count that is kept in the *sa_ref* field. An array element can be deleted (together with all references to it) when its *sa_ref* value is *null* and its value is the default value.

Skip, muskip, box, and token registers use two word nodes, their values are stored in the *sa_ptr* field. Count and dimen registers use three word nodes, their values are stored in the *sa_int* resp. *sa_dim* field in the third word; the *sa_ptr* field is used under the name *sa_num* to store the register number. Mark classes use four word nodes. The last three words contain the five types of current marks

```

define sa_lev  $\equiv$  sa_used { grouping level for the current value }
define pointer_node_size = 2 { size of an element with a pointer value }
define sa_type( $\#$ )  $\equiv$  (sa_index( $\#$ ) div 16) { type part of combined type/index }
define sa_ref( $\#$ )  $\equiv$  info( $\#$  + 1) { reference count of a sparse array element }
define sa_ptr( $\#$ )  $\equiv$  link( $\#$  + 1) { a pointer value }

define word_node_size = 3 { size of an element with a word value }
define sa_num  $\equiv$  sa_ptr { the register number }
define sa_int( $\#$ )  $\equiv$  mem[ $\#$  + 2].int { an integer }
define sa_dim( $\#$ )  $\equiv$  mem[ $\#$  + 2].sc { a dimension (a somewhat esoteric distinction) }

define mark_class_node_size = 4 { size of an element for a mark class }

define fetch_box( $\#$ )  $\equiv$  { fetch box(cur_val) }
  if cur_val < 256 then  $\# \leftarrow$  box(cur_val)
  else begin find_sa_element(box_val, cur_val, false);
    if cur_ptr = null then  $\# \leftarrow$  null else  $\# \leftarrow$  sa_ptr(cur_ptr);
  end

(Create a new array element of type t with index i 1817)  $\equiv$ 
if t = mark_val then { a mark class }
  begin cur_ptr  $\leftarrow$  get_node(mark_class_node_size); mem[cur_ptr + 1]  $\leftarrow$  sa_null;
  mem[cur_ptr + 2]  $\leftarrow$  sa_null; mem[cur_ptr + 3]  $\leftarrow$  sa_null;
  end
else begin if t  $\leq$  dimen_val then { a count or dimen register }
  begin cur_ptr  $\leftarrow$  get_node(word_node_size); sa_int(cur_ptr)  $\leftarrow$  0; sa_num(cur_ptr)  $\leftarrow$  n;
  end
else begin cur_ptr  $\leftarrow$  get_node(pointer_node_size);
  if t  $\leq$  mu_val then { a skip or muskip register }
    begin sa_ptr(cur_ptr)  $\leftarrow$  zero_glue; add_glue_ref(zero_glue);
    end
  else sa_ptr(cur_ptr)  $\leftarrow$  null; { a box or token list register }
  end;
  sa_ref(cur_ptr)  $\leftarrow$  null; { all registers have a reference count }
end;
  sa_index(cur_ptr)  $\leftarrow$  16 * t + i; sa_lev(cur_ptr)  $\leftarrow$  level_one

```

This code is used in section 1816.

1818. The *delete_sa_ref* procedure is called when a pointer to an array element representing a register is being removed; this means that the reference count should be decreased by one. If the reduced reference count is *null* and the register has been (globally) assigned its default value the array element should disappear, possibly together with some index nodes. This procedure will never be used for mark class nodes.

```

define add_sa_ref(#)  $\equiv$  incr(sa_ref(#)) { increase reference count }
define change_box(#)  $\equiv$  { change box(cur_val), the eq_level stays the same }
    if cur_val < 256 then box(cur_val)  $\leftarrow$  # else set_sa_box(#)
define set_sa_box(#)  $\equiv$ 
    begin find_sa_element(box_val, cur_val, false);
    if cur_ptr  $\neq$  null then
        begin sa_ptr(cur_ptr)  $\leftarrow$  #; add_sa_ref(cur_ptr); delete_sa_ref(cur_ptr);
        end;
    end

⟨ Declare  $\varepsilon$ -TEX procedures for tracing and input 306 ⟩  $\equiv$ 
procedure delete_sa_ref(q : pointer); { reduce reference count }
    label exit;
    var p: pointer; { for list manipulations }
        i: small_number; { a four bit index }
        s: small_number; { size of a node }
    begin decr(sa_ref(q));
    if sa_ref(q)  $\neq$  null then return;
    if sa_index(q) < dimen_val_limit then
        if sa_int(q) = 0 then s  $\leftarrow$  word_node_size
        else return
    else begin if sa_index(q) < mu_val_limit then
        if sa_ptr(q) = zero_glue then delete_glue_ref(zero_glue)
        else return
        else if sa_ptr(q)  $\neq$  null then return;
        s  $\leftarrow$  pointer_node_size;
        end;
    repeat i  $\leftarrow$  hex_dig4(sa_index(q)); p  $\leftarrow$  q; q  $\leftarrow$  link(p); free_node(p, s);
    if q = null then { the whole tree has been freed }
        begin sa_root[i]  $\leftarrow$  null; return;
        end;
        delete_sa_ptr; s  $\leftarrow$  index_node_size; { node q is an index node }
    until sa_used(q) > 0;
exit: end;

```

1819. The *print_sa_num* procedure prints the register number corresponding to an array element.

```

⟨ Basic printing procedures 57 ⟩  $\equiv$ 
procedure print_sa_num(q : pointer); { print register number }
    var n: halfword; { the register number }
    begin if sa_index(q) < dimen_val_limit then n  $\leftarrow$  sa_num(q) { the easy case }
    else begin n  $\leftarrow$  hex_dig4(sa_index(q)); q  $\leftarrow$  link(q); n  $\leftarrow$  n + 16 * sa_index(q); q  $\leftarrow$  link(q);
        n  $\leftarrow$  n + 256 * (sa_index(q) + 16 * sa_index(link(q)));
        end;
    print_int(n);
end;

```

1820. Here is a procedure that displays the contents of an array element symbolically. It is used under similar circumstances as is *restore_trace* (together with *show_eqtb*) for the quantities kept in the *eqtb* array.

```

⟨ Declare  $\varepsilon$ -TeX procedures for tracing and input 306 ⟩ +≡
stat procedure show_sa(p : pointer; s : str_number);
var t: small_number; { the type of element }
begin begin_diagnostic; print_char("{"); print(s); print_char("␣");
if p = null then print_char("?") { this can't happen }
else begin t ← sa_type(p);
  if t < box_val then print_cmd_chr(register, p)
  else if t = box_val then
    begin print_esc("box"); print_sa_num(p);
    end
  else if t = tok_val then print_cmd_chr(toks_register, p)
  else print_char("?"); { this can't happen either }
print_char("=");
if t = int_val then print_int(sa_int(p))
else if t = dimen_val then
  begin print_scaled(sa_dim(p)); print("pt");
  end
else begin p ← sa_ptr(p);
  if t = glue_val then print_spec(p, "pt")
  else if t = mu_val then print_spec(p, "mu")
  else if t = box_val then
    if p = null then print("void")
    else begin depth_threshold ← 0; breadth_max ← 1; show_node_list(p);
    end
  else if t = tok_val then
    begin if p ≠ null then show_token_list(link(p), null, 32);
    end
    else print_char("?"); { this can't happen either }
  end;
end;
print_char("}"); end_diagnostic(false);
end;
tats

```

1821. Here we compute the pointer to the current mark of type *t* and mark class *cur_val*.

```

⟨ Compute the mark pointer for mark type t and class cur_val 1821 ⟩ ≡
begin find_sa_element(mark_val, cur_val, false);
if cur_ptr ≠ null then
  if odd(t) then cur_ptr ← link(cur_ptr + (t div 2) + 1)
  else cur_ptr ← info(cur_ptr + (t div 2) + 1);
end

```

This code is used in section 412.

1822. The current marks for all mark classes are maintained by the *vsplit* and *fire_up* routines and are finally destroyed (for INITEX only) by the *final_cleanup* routine. Apart from updating the current marks when mark nodes are encountered, these routines perform certain actions on all existing mark classes. The recursive *do_marks* procedure walks through the whole tree or a subtree of existing mark class nodes and preforms certain actions indicted by its first parameter *a*, the action code. The second parameter *l* indicates the level of recursion (at most four); the third parameter points to a nonempty tree or subtree. The result is *true* if the complete tree or subtree has been deleted.

```

define vsplit_init  $\equiv$  0 { action code for vsplit initialization }
define fire_up_init  $\equiv$  1 { action code for fire_up initialization }
define fire_up_done  $\equiv$  2 { action code for fire_up completion }
define destroy_marks  $\equiv$  3 { action code for final_cleanup }

define sa_top_mark( $\#$ )  $\equiv$  info( $\# + 1$ ) { \topmarksn }
define sa_first_mark( $\#$ )  $\equiv$  link( $\# + 1$ ) { \firstmarksn }
define sa_bot_mark( $\#$ )  $\equiv$  info( $\# + 2$ ) { \botmarksn }
define sa_split_first_mark( $\#$ )  $\equiv$  link( $\# + 2$ ) { \splitfirstmarksn }
define sa_split_bot_mark( $\#$ )  $\equiv$  info( $\# + 3$ ) { \splitbotmarksn }

 $\langle$  Declare the function called do_marks 1822  $\rangle \equiv$ 
function do_marks(a, l : small_number; q : pointer): boolean;
  var i: small_number; { a four bit index }
  begin if l < 4 then { q is an index node }
    begin for i  $\leftarrow$  0 to 15 do
      begin get_sa_ptr;
      if cur_ptr  $\neq$  null then
        if do_marks(a, l + 1, cur_ptr) then delete_sa_ptr;
      end;
      if sa_used(q) = 0 then
        begin free_node(q, index_node_size); q  $\leftarrow$  null;
        end;
      end
    else { q is the node for a mark class }
      begin case a of
         $\langle$  Cases for do_marks 1823  $\rangle$ 
      end; { there are no other cases }
      if sa_bot_mark(q) = null then
        if sa_split_bot_mark(q) = null then
          begin free_node(q, mark_class_node_size); q  $\leftarrow$  null;
          end;
        end; do_marks  $\leftarrow$  (q = null);
      end;

```

This code is used in section 1152.

1823. At the start of the *vsplit* routine the existing *split_fist_mark* and *split_bot_mark* are discarded.

```

 $\langle$  Cases for do_marks 1823  $\rangle \equiv$ 
vsplit_init: if sa_split_first_mark(q)  $\neq$  null then
  begin delete_token_ref(sa_split_first_mark(q)); sa_split_first_mark(q)  $\leftarrow$  null;
  delete_token_ref(sa_split_bot_mark(q)); sa_split_bot_mark(q)  $\leftarrow$  null;
  end;

```

See also sections 1825, 1826, and 1828.

This code is used in section 1822.

1824. We use again the fact that *split_first_mark* = *null* if and only if *split_bot_mark* = *null*.

```

⟨ Update the current marks for vsplit 1824 ⟩ ≡
  begin find_sa_element(mark_val, mark_class(p), true);
  if sa_split_first_mark(cur_ptr) = null then
    begin sa_split_first_mark(cur_ptr) ← mark_ptr(p); add_token_ref(mark_ptr(p));
    end
  else delete_token_ref(sa_split_bot_mark(cur_ptr));
  sa_split_bot_mark(cur_ptr) ← mark_ptr(p); add_token_ref(mark_ptr(p));
  end

```

This code is used in section 1154.

1825. At the start of the *fire_up* routine the old *top_mark* and *first_mark* are discarded, whereas the old *bot_mark* becomes the new *top_mark*. An empty new *top_mark* token list is, however, discarded as well in order that mark class nodes can eventually be released. We use again the fact that *bot_mark* ≠ *null* implies *first_mark* ≠ *null*; it also knows that *bot_mark* = *null* implies *top_mark* = *first_mark* = *null*.

```

⟨ Cases for do_marks 1823 ⟩ +≡
fire_up_init: if sa_bot_mark(q) ≠ null then
  begin if sa_top_mark(q) ≠ null then delete_token_ref(sa_top_mark(q));
  delete_token_ref(sa_first_mark(q)); sa_first_mark(q) ← null;
  if link(sa_bot_mark(q)) = null then { an empty token list }
    begin delete_token_ref(sa_bot_mark(q)); sa_bot_mark(q) ← null;
    end
  else add_token_ref(sa_bot_mark(q));
  sa_top_mark(q) ← sa_bot_mark(q);
  end;

```

```

1826. ⟨ Cases for do_marks 1823 ⟩ +≡
fire_up_done: if (sa_top_mark(q) ≠ null) ∧ (sa_first_mark(q) = null) then
  begin sa_first_mark(q) ← sa_top_mark(q); add_token_ref(sa_top_mark(q));
  end;

```

```

1827. ⟨ Update the current marks for fire_up 1827 ⟩ ≡
  begin find_sa_element(mark_val, mark_class(p), true);
  if sa_first_mark(cur_ptr) = null then
    begin sa_first_mark(cur_ptr) ← mark_ptr(p); add_token_ref(mark_ptr(p));
    end;
  if sa_bot_mark(cur_ptr) ≠ null then delete_token_ref(sa_bot_mark(cur_ptr));
  sa_bot_mark(cur_ptr) ← mark_ptr(p); add_token_ref(mark_ptr(p));
  end

```

This code is used in section 1189.

1828. Here we use the fact that the five current mark pointers in a mark class node occupy the same locations as the the first five pointers of an index node. For systems using a run-time switch to distinguish between VIRTEX and INITEX, the codewords ‘**init** ... **tini**’ surrounding the following piece of code should be removed.

```

⟨ Cases for do_marks 1823 ⟩ +≡
  init destroy_marks: for  $i \leftarrow top\_mark\_code$  to split_bot_mark_code do
    begin get_sa_ptr;
    if  $cur\_ptr \neq null$  then
      begin delete_token_ref( $cur\_ptr$ ); put_sa_ptr( $null$ );
      end;
    end;
  tini

```

1829. The command code *register* is used for ‘\count’, ‘\dimen’, etc., as well as for references to sparse array elements defined by ‘\countdef’, etc.

```

⟨ Cases of register for print_cmd_chr 1829 ⟩ ≡
  begin if ( $chr\_code < mem\_bot$ )  $\vee$  ( $chr\_code > lo\_mem\_stat\_max$ ) then  $cmd \leftarrow sa\_type(chr\_code)$ 
  else begin  $cmd \leftarrow chr\_code - mem\_bot$ ;  $chr\_code \leftarrow null$ ;
  end;
  if  $cmd = int\_val$  then print_esc("count")
  else if  $cmd = dimen\_val$  then print_esc("dimen")
    else if  $cmd = glue\_val$  then print_esc("skip")
      else print_esc("muskip");
  if  $chr\_code \neq null$  then print_sa_num( $chr\_code$ );
  end

```

This code is used in section 438.

1830. Similarly the command code *toks_register* is used for ‘\toks’ as well as for references to sparse array elements defined by ‘\toksdef’.

```

⟨ Cases of toks_register for print_cmd_chr 1830 ⟩ ≡
  begin print_esc("toks");
  if  $chr\_code \neq mem\_bot$  then print_sa_num( $chr\_code$ );
  end

```

This code is used in section 288.

1831. When a shorthand definition for an element of one of the sparse arrays is destroyed, we must reduce the reference count.

```

⟨ Cases for eq_destroy 1831 ⟩ ≡
toks_register, register: if ( $equiv\_field(w) < mem\_bot$ )  $\vee$  ( $equiv\_field(w) > lo\_mem\_stat\_max$ ) then
  delete_sa_ref( $equiv\_field(w)$ );

```

This code is used in section 297.

1832. The task to maintain (change, save, and restore) register values is essentially the same when the register is realized as sparse array element or entry in *eqtb*. The global variable *sa_chain* is the head of a linked list of entries saved at the topmost level *sa_level*; the lists for lower levels are kept in special save stack entries.

```

⟨ Global variables 13 ⟩ +≡
sa_chain: pointer; { chain of saved sparse array entries }
sa_level: quarterword; { group level for sa_chain }

```

1833. \langle Set initial values of key variables 21 $\rangle + \equiv$
 $sa_chain \leftarrow null; sa_level \leftarrow level_zero;$

1834. The individual saved items are kept in pointer or word nodes similar to those used for the array elements: a word node with value zero is, however, saved as pointer node with the otherwise impossible sa_index value tok_val_limit .

```

define  $sa\_loc \equiv sa\_ref$  { location of saved item }
 $\langle$  Declare  $\varepsilon$ -TeX procedures for tracing and input 306  $\rangle + \equiv$ 
procedure  $sa\_save(p : pointer);$  { saves value of  $p$  }
  var  $q : pointer;$  { the new save node }
   $i : quarterword;$  { index field of node }
  begin if  $cur\_level \neq sa\_level$  then
    begin  $check\_full\_save\_stack;$   $save\_type(save\_ptr) \leftarrow restore\_sa;$   $save\_level(save\_ptr) \leftarrow sa\_level;$ 
     $save\_index(save\_ptr) \leftarrow sa\_chain;$   $incr(save\_ptr);$   $sa\_chain \leftarrow null;$   $sa\_level \leftarrow cur\_level;$ 
    end;
     $i \leftarrow sa\_index(p);$ 
    if  $i < dimen\_val\_limit$  then
      begin if  $sa\_int(p) = 0$  then
        begin  $q \leftarrow get\_node(pointer\_node\_size);$   $i \leftarrow tok\_val\_limit;$ 
        end
      else begin  $q \leftarrow get\_node(word\_node\_size);$   $sa\_int(q) \leftarrow sa\_int(p);$ 
      end;
       $sa\_ptr(q) \leftarrow null;$ 
      end
    else begin  $q \leftarrow get\_node(pointer\_node\_size);$   $sa\_ptr(q) \leftarrow sa\_ptr(p);$ 
    end;
     $sa\_loc(q) \leftarrow p;$   $sa\_index(q) \leftarrow i;$   $sa\_lev(q) \leftarrow sa\_lev(p);$   $link(q) \leftarrow sa\_chain;$   $sa\_chain \leftarrow q;$   $add\_sa\_ref(p);$ 
    end;

```

1835. \langle Declare ε -TeX procedures for tracing and input 306 $\rangle + \equiv$
procedure $sa_destroy(p : pointer);$ { destroy value of p }
begin if $sa_index(p) < mu_val_limit$ **then** $delete_glue_ref(sa_ptr(p))$
else if $sa_ptr(p) \neq null$ **then**
 if $sa_index(p) < box_val_limit$ **then** $flush_node_list(sa_ptr(p))$
 else $delete_token_ref(sa_ptr(p));$
end;

1836. The procedure *sa_def* assigns a new value to sparse array elements, and saves the former value if appropriate. This procedure is used only for skip, muskip, box, and token list registers. The counterpart of *sa_def* for count and dimen registers is called *sa_w_def*.

```

define sa_define(#)  $\equiv$ 
  if e then
    if global then gsa_def(#) else sa_def(#)
  else define
define sa_def_box  $\equiv$  { assign cur_box to box(cur_val) }
  begin find_sa_element(box_val, cur_val, true);
  if global then gsa_def(cur_ptr, cur_box) else sa_def(cur_ptr, cur_box);
  end

define sa_word_define(#)  $\equiv$ 
  if e then
    if global then gsa_w_def(#) else sa_w_def(#)
  else word_define(#)

⟨ Declare  $\varepsilon$ -TEX procedures for tracing and input 306 ⟩  $\equiv$ 
procedure sa_def(p : pointer; e : halfword); { new data for sparse array elements }
  begin add_sa_ref(p);
  if sa_ptr(p) = e then
    begin stat if tracing_assigns > 0 then show_sa(p, "reassigning");
    tats
    sa_destroy(p);
    end
  else begin stat if tracing_assigns > 0 then show_sa(p, "changing");
  tats
  if sa_lev(p) = cur_level then sa_destroy(p) else sa_save(p);
  sa_lev(p)  $\leftarrow$  cur_level; sa_ptr(p)  $\leftarrow$  e;
  stat if tracing_assigns > 0 then show_sa(p, "into");
  tats
  end;
  delete_sa_ref(p);
  end;

procedure sa_w_def(p : pointer; w : integer);
  begin add_sa_ref(p);
  if sa_int(p) = w then
    begin stat if tracing_assigns > 0 then show_sa(p, "reassigning");
    tats
    end
  else begin stat if tracing_assigns > 0 then show_sa(p, "changing");
  tats
  if sa_lev(p)  $\neq$  cur_level then sa_save(p);
  sa_lev(p)  $\leftarrow$  cur_level; sa_int(p)  $\leftarrow$  w;
  stat if tracing_assigns > 0 then show_sa(p, "into");
  tats
  end;
  delete_sa_ref(p);
  end;

```


1837. The *sa_def* and *sa_w_def* routines take care of local definitions. Global definitions are done in almost the same way, but there is no need to save old values, and the new value is associated with *level_one*.

⟨ Declare ε -TeX procedures for tracing and input 306 ⟩ +≡

```

procedure gsa_def(p : pointer; e : halfword); { global sa_def }
  begin add_sa_ref(p);
  stat if tracing_assigns > 0 then show_sa(p, "globally_changing");
  tats
  sa_destroy(p); sa_lev(p) ← level_one; sa_ptr(p) ← e;
  stat if tracing_assigns > 0 then show_sa(p, "into");
  tats
  delete_sa_ref(p);
  end;

procedure gsa_w_def(p : pointer; w : integer); { global sa_w_def }
  begin add_sa_ref(p);
  stat if tracing_assigns > 0 then show_sa(p, "globally_changing");
  tats
  sa_lev(p) ← level_one; sa_int(p) ← w;
  stat if tracing_assigns > 0 then show_sa(p, "into");
  tats
  delete_sa_ref(p);
  end;

```

1838. The *sa_restore* procedure restores the sparse array entries pointed at by *sa_chain*.

⟨ Declare ε -TeX procedures for tracing and input 306 ⟩ +≡

```

procedure sa_restore;
  var p: pointer; { sparse array element }
  begin repeat p ← sa_loc(sa_chain);
    if sa_lev(p) = level_one then
      begin if sa_index(p) ≥ dimen_val_limit then sa_destroy(sa_chain);
        stat if tracing_restores > 0 then show_sa(p, "retaining");
        tats
        end
      else begin if sa_index(p) < dimen_val_limit then
        if sa_index(sa_chain) < dimen_val_limit then sa_int(p) ← sa_int(sa_chain)
        else sa_int(p) ← 0
        else begin sa_destroy(p); sa_ptr(p) ← sa_ptr(sa_chain);
          end;
          sa_lev(p) ← sa_lev(sa_chain);
          stat if tracing_restores > 0 then show_sa(p, "restoring");
          tats
          end;
          delete_sa_ref(p); p ← sa_chain; sa_chain ← link(p);
          if sa_index(p) < dimen_val_limit then free_node(p, word_node_size)
          else free_node(p, pointer_node_size);
        until sa_chain = null;
      end;
  end;

```

1839. When the value of *last_line_fit* is positive, the last line of a (partial) paragraph is treated in a special way and we need additional fields in the active nodes.

```

define active_node_size_extended = 5 { number of words in extended active nodes }
define active_short(#)  $\equiv$  mem[# + 3].sc { shortfall of this line }
define active_glue(#)  $\equiv$  mem[# + 4].sc { corresponding glue stretch or shrink }

⟨Global variables 13⟩  $\equiv$ 
last_line_fill: pointer; { the par_fill_skip glue node of the new paragraph }
do_last_line_fit: boolean; { special algorithm for last line of paragraph? }
active_node_size: small_number; { number of words in active nodes }
fill_width: array [0 .. 2] of scaled; { infinite stretch components of par_fill_skip }
best_pl_short: array [very_loose_fit .. tight_fit] of scaled; { shortfall corresponding to minimal_demerits }
best_pl_glue: array [very_loose_fit .. tight_fit] of scaled; { corresponding glue stretch or shrink }

```

1840. The new algorithm for the last line requires that the stretchability of *par_fill_skip* is infinite and the stretchability of *left_skip* plus *right_skip* is finite.

```

⟨Check for special treatment of last line of paragraph 1840⟩  $\equiv$ 
  do_last_line_fit  $\leftarrow$  false; active_node_size  $\leftarrow$  active_node_size_normal; { just in case }
  if last_line_fit > 0 then
    begin q  $\leftarrow$  glue_ptr(last_line_fill);
    if (stretch(q) > 0)  $\wedge$  (stretch_order(q) > normal) then
      if (background[3] = 0)  $\wedge$  (background[4] = 0)  $\wedge$  (background[5] = 0) then
        begin do_last_line_fit  $\leftarrow$  true; active_node_size  $\leftarrow$  active_node_size_extended; fill_width[0]  $\leftarrow$  0;
        fill_width[1]  $\leftarrow$  0; fill_width[2]  $\leftarrow$  0; fill_width[stretch_order(q) - 1]  $\leftarrow$  stretch(q);
        end;
      end
    end

```

This code is used in section 1001.

1841. ⟨Other local variables for *try_break* 1004⟩ \equiv
g: *scaled*; { glue stretch or shrink of test line, adjustment for last line }

1842. Here we initialize the additional fields of the first active node representing the beginning of the paragraph.

```

⟨Initialize additional fields of the first active node 1842⟩  $\equiv$ 
  begin active_short(q)  $\leftarrow$  0; active_glue(q)  $\leftarrow$  0;
  end

```

This code is used in section 1038.

1843. Here we compute the adjustment g and badness b for a line from r to the end of the paragraph. When any of the criteria for adjustment is violated we fall through to the normal algorithm.

The last line must be too short, and have infinite stretch entirely due to *par-fill-skip*.

```

⟨Perform computations for last line and goto found 1843⟩ ≡
  begin if (active_short( $r$ ) = 0)  $\vee$  (active_glue( $r$ )  $\leq$  0) then goto not_found;
    { previous line was neither stretched nor shrunk, or was infinitely bad }
  if (cur_active_width[3]  $\neq$  fill_width[0])  $\vee$  (cur_active_width[4]  $\neq$  fill_width[1])  $\vee$ 
    (cur_active_width[5]  $\neq$  fill_width[2]) then goto not_found;
    { infinite stretch of this line not entirely due to par-fill-skip }
  if active_short( $r$ ) > 0 then  $g \leftarrow$  cur_active_width[2]
  else  $g \leftarrow$  cur_active_width[6];
  if  $g \leq 0$  then goto not_found; { no finite stretch resp. no shrink }
  arith_error  $\leftarrow$  false;  $g \leftarrow$  fract( $g$ , active_short( $r$ ), active_glue( $r$ ), max_dimen);
  if last_line_fit < 1000 then  $g \leftarrow$  fract( $g$ , last_line_fit, 1000, max_dimen);
  if arith_error then
    if active_short( $r$ ) > 0 then  $g \leftarrow$  max_dimen else  $g \leftarrow$   $-$ max_dimen;
  if  $g > 0$  then ⟨Set the value of  $b$  to the badness of the last line for stretching, compute the corresponding
    fit_class, and goto found 1844⟩
  else if  $g < 0$  then ⟨Set the value of  $b$  to the badness of the last line for shrinking, compute the
    corresponding fit_class, and goto found 1845⟩;
not_found: end

```

This code is used in section 1026.

1844. These badness computations are rather similar to those of the standard algorithm, with the adjustment amount g replacing the *shortfall*.

```

⟨Set the value of  $b$  to the badness of the last line for stretching, compute the corresponding fit_class, and
  goto found 1844⟩ ≡
  begin if  $g >$  shortfall then  $g \leftarrow$  shortfall;
  if  $g >$  7230584 then
    if cur_active_width[2] < 1663497 then
      begin  $b \leftarrow$  inf_bad; fit_class  $\leftarrow$  very_loose_fit; goto found;
    end;
   $b \leftarrow$  badness( $g$ , cur_active_width[2]);
  if  $b >$  12 then
    if  $b >$  99 then fit_class  $\leftarrow$  very_loose_fit
    else fit_class  $\leftarrow$  loose_fit
  else fit_class  $\leftarrow$  decent_fit;
  goto found;
end

```

This code is used in section 1843.

```

1845. ⟨Set the value of  $b$  to the badness of the last line for shrinking, compute the corresponding fit_class,
  and goto found 1845⟩ ≡
  begin if  $-g >$  cur_active_width[6] then  $g \leftarrow$   $-$ cur_active_width[6];
   $b \leftarrow$  badness( $-g$ , cur_active_width[6]);
  if  $b >$  12 then fit_class  $\leftarrow$  tight_fit else fit_class  $\leftarrow$  decent_fit;
  goto found;
end

```

This code is used in section 1843.

1846. Vanishing values of *shortfall* and *g* indicate that the last line is not adjusted.

```

⟨Adjust the additional data for last line 1846⟩ ≡
  begin if cur_p = null then shortfall ← 0;
  if shortfall > 0 then g ← cur_active_width[2]
  else if shortfall < 0 then g ← cur_active_width[6]
  else g ← 0;
  end

```

This code is used in section 1025.

1847. For each feasible break we record the shortfall and glue stretch or shrink (or adjustment).

```

⟨Store additional data for this feasible break 1847⟩ ≡
  begin best_pl_short[fit_class] ← shortfall; best_pl_glue[fit_class] ← g;
  end

```

This code is used in section 1029.

1848. Here we save these data in the active node representing a potential line break.

```

⟨Store additional data in the new active node 1848⟩ ≡
  begin active_short(q) ← best_pl_short[fit_class]; active_glue(q) ← best_pl_glue[fit_class];
  end

```

This code is used in section 1019.

1849. ⟨Print additional data in the new active node 1849⟩ ≡

```

  begin print("s="); print_scaled(active_short(q));
  if cur_p = null then print("a=") else print("g=");
  print_scaled(active_glue(q));
  end

```

This code is used in section 1020.

1850. Here we either reset *do_last_line_fit* or adjust the *par_fill_skip* glue.

```

⟨Adjust the final line of the paragraph 1850⟩ ≡
  if active_short(best_bet) = 0 then do_last_line_fit ← false
  else begin q ← new_spec(glue_ptr(last_line_fill)); delete_glue_ref(glue_ptr(last_line_fill));
    width(q) ← width(q) + active_short(best_bet) - active_glue(best_bet); stretch(q) ← 0;
    glue_ptr(last_line_fill) ← q;
  end

```

This code is used in section 1037.

1851. When reading `\patterns` while `\savinghyphcodes` is positive the current *lc_code* values are stored together with the hyphenation patterns for the current language. They will later be used instead of the *lc_code* values for hyphenation purposes.

The *lc_code* values are stored in the linked trie analogous to patterns p_1 of length 1, with *hyph_root* = *trie_r*[0] replacing *trie_root* and *lc_code*(p_1) replacing the *trie_op* code. This allows to compress and pack them together with the patterns with minimal changes to the existing code.

```

define hyph_root ≡ trie_r[0] { root of the linked trie for hyph_codes }

```

⟨Initialize table entries (done by INITEX only) 182⟩ +≡

```

  hyph_root ← 0; hyph_start ← 0;

```

1852. \langle Store hyphenation codes for current language 1852 $\rangle \equiv$

```

begin  $c \leftarrow cur\_lang$ ;  $first\_child \leftarrow false$ ;  $p \leftarrow 0$ ;
repeat  $q \leftarrow p$ ;  $p \leftarrow trie\_r[q]$ ;
until  $(p = 0) \vee (c \leq so(trie\_c[p]))$ ;
if  $(p = 0) \vee (c < so(trie\_c[p]))$  then
   $\langle$  Insert a new trie node between  $q$  and  $p$ , and make  $p$  point to it 1139  $\rangle$ ;
 $q \leftarrow p$ ; { now node  $q$  represents  $cur\_lang$  }
 $\langle$  Store all current  $lc\_code$  values 1853  $\rangle$ ;
end

```

This code is used in section 1135.

1853. We store all nonzero lc_code values, overwriting any previously stored values (and possibly wasting a few trie nodes that were used previously and are not needed now). We always store at least one lc_code value such that $hyph_index$ (defined below) will not be zero.

\langle Store all current lc_code values 1853 $\rangle \equiv$

```

 $p \leftarrow trie\_l[q]$ ;  $first\_child \leftarrow true$ ;
for  $c \leftarrow 0$  to 255 do
  if  $(lc\_code(c) > 0) \vee ((c = 255) \wedge first\_child)$  then
    begin if  $p = 0$  then  $\langle$  Insert a new trie node between  $q$  and  $p$ , and make  $p$  point to it 1139  $\rangle$ 
    else  $trie\_c[p] \leftarrow si(c)$ ;
     $trie\_o[p] \leftarrow qi(lc\_code(c))$ ;  $q \leftarrow p$ ;  $p \leftarrow trie\_r[q]$ ;  $first\_child \leftarrow false$ ;
    end;
  if  $first\_child$  then  $trie\_l[q] \leftarrow 0$  else  $trie\_r[q] \leftarrow 0$ 

```

This code is used in section 1852.

1854. We must avoid to “take” location 1, in order to distinguish between lc_code values and patterns.

\langle Pack all stored $hyph_codes$ 1854 $\rangle \equiv$

```

begin if  $trie\_root = 0$  then
  for  $p \leftarrow 0$  to 255 do  $trie\_min[p] \leftarrow p + 2$ ;
 $first\_fit(hyph\_root)$ ;  $trie\_pack(hyph\_root)$ ;  $hyph\_start \leftarrow trie\_ref[hyph\_root]$ ;
end

```

This code is used in section 1141.

1855. The global variable $hyph_index$ will point to the hyphenation codes for the current language.

```

define  $set\_hyph\_index \equiv$  { set  $hyph\_index$  for current language }
  if  $trie\_char(hyph\_start + cur\_lang) \neq qi(cur\_lang)$  then  $hyph\_index \leftarrow 0$ 
    { no hyphenation codes for  $cur\_lang$  }
  else  $hyph\_index \leftarrow trie\_link(hyph\_start + cur\_lang)$ 
define  $set\_lc\_code(\#) \equiv$  { set  $hc[0]$  to hyphenation or lc code for  $\#$  }
  if  $hyph\_index = 0$  then  $hc[0] \leftarrow lc\_code(\#)$ 
  else if  $trie\_char(hyph\_index + \#) \neq qi(\#)$  then  $hc[0] \leftarrow 0$ 
    else  $hc[0] \leftarrow qo(trie\_op(hyph\_index + \#))$ 

```

\langle Global variables 13 $\rangle \equiv$

```

 $hyph\_start$ :  $trie\_pointer$ ; { root of the packed trie for  $hyph\_codes$  }
 $hyph\_index$ :  $trie\_pointer$ ; { pointer to hyphenation codes for  $cur\_lang$  }

```

1856. When *saving_vdiscards* is positive then the glue, kern, and penalty nodes removed by the page builder or by `\vsplit` from the top of a vertical list are saved in special lists instead of being discarded.

```
define tail_page_disc  $\equiv$  disc_ptr[copy_code] { last item removed by page builder }
define page_disc  $\equiv$  disc_ptr[last_box_code] { first item removed by page builder }
define split_disc  $\equiv$  disc_ptr[vsplit_code] { first item removed by \vsplit }
```

\langle Global variables 13 $\rangle + \equiv$

```
disc_ptr: array [copy_code .. vsplit_code] of pointer; { list pointers }
```

1857. \langle Set initial values of key variables 21 $\rangle + \equiv$

```
page_disc  $\leftarrow$  null; split_disc  $\leftarrow$  null;
```

1858. The `\pagediscards` and `\splitdiscards` commands share the command code *un_vbox* with `\unvbox` and `\uncopy`, they are distinguished by their *chr_code* values *last_box_code* and *vsplit_code*. These *chr_code* values are larger than *box_code* and *copy_code*.

\langle Generate all ε -TEX primitives 1646 $\rangle + \equiv$

```
primitive("pagediscards", un_vbox, last_box_code);
primitive("splitdiscards", un_vbox, vsplit_code);
```

1859. \langle Cases of *un_vbox* for *print_cmd_chr* 1859 $\rangle \equiv$

```
else if chr_code = last_box_code then print_esc("pagediscards")
else if chr_code = vsplit_code then print_esc("splitdiscards")
```

This code is used in section 1284.

1860. \langle Handle saved items and `goto done` 1860 $\rangle \equiv$

```
begin link(tail)  $\leftarrow$  disc_ptr[cur_chr]; disc_ptr[cur_chr]  $\leftarrow$  null; goto done;
end
```

This code is used in section 1286.

1861. The `\interlinepenalties`, `\clubpenalties`, `\widowpenalties`, and `\displaywidowpenalties` commands allow to define arrays of penalty values to be used instead of the corresponding single values.

```
define inter_line_penalties_ptr  $\equiv$  equiv(inter_line_penalties_loc)
define club_penalties_ptr  $\equiv$  equiv(club_penalties_loc)
define widow_penalties_ptr  $\equiv$  equiv(widow_penalties_loc)
define display_widow_penalties_ptr  $\equiv$  equiv(display_widow_penalties_loc)
```

\langle Generate all ε -TEX primitives 1646 $\rangle + \equiv$

```
primitive("interlinepenalties", set_shape, inter_line_penalties_loc);
primitive("clubpenalties", set_shape, club_penalties_loc);
primitive("widowpenalties", set_shape, widow_penalties_loc);
primitive("displaywidowpenalties", set_shape, display_widow_penalties_loc);
```

1862. \langle Cases of *set_shape* for *print_cmd_chr* 1862 $\rangle \equiv$

```
inter_line_penalties_loc: print_esc("interlinepenalties");
club_penalties_loc: print_esc("clubpenalties");
widow_penalties_loc: print_esc("widowpenalties");
display_widow_penalties_loc: print_esc("displaywidowpenalties");
```

This code is used in section 288.

1863. $\langle \text{Fetch a penalties array element } 1863 \rangle \equiv$

```

begin scan_int;
if (equiv(m) = null)  $\vee$  (cur_val < 0) then cur_val  $\leftarrow$  0
else begin if cur_val > penalty(equiv(m)) then cur_val  $\leftarrow$  penalty(equiv(m));
    cur_val  $\leftarrow$  penalty(equiv(m) + cur_val);
end;
end

```

This code is used in section 449.

1864. System-dependent changes. This section should be replaced, if necessary, by any special modifications of the program that are necessary to make TeX work at a particular installation. It is usually best to design your change file so that all changes to previous sections preserve the section numbering; then everybody's version will be consistent with the published program. More extensive changes, which introduce new sections, can be inserted here; then only the index itself will get a new section number.

1865. Index. Here is where you can find all uses of each identifier in the program, with underlined entries pointing to where the identifier was defined. If the identifier is only one letter long, however, you get to see only the underlined entries. *All references are to section numbers instead of page numbers.*

This index also lists error messages and other aspects of the program that you might want to look up some day. For example, the entry for “system dependencies” lists all sections that should receive special attention from people who are installing TeX in a new operating environment. A list of various things that can’t happen appears under “this can’t happen”. Approximately 40 sections are listed under “inner loop”; these account for about 60% of TeX’s running time, exclusive of input and output.

- ** : 37, 560.
- * : 192, 194, 196, 335, 382, 674, 1030, 1181, 1599.
- > : 316.
- => : 385.
- ??? : 59.
- ? : 83.
- @ : 1030.
- @@ : 1020.
- a : 47, 102, 122, 236, 303, 544, 545, 549, 586, 597, 624, 678, 686, 698, 865, 896, 912, 926, 1251, 1299, 1370, 1387, 1412, 1433, 1511, 1597, 1634, 1676, 1779, 1790, 1794, 1796, 1822.
- A <box> was supposed to... : 1260.
- a_close : 28, 51, 351, 511, 512, 1451, 1511, 1619, 1623.
- a_leaders : 167, 207, 653, 655, 662, 664, 735, 744, 830, 845, 1247, 1248, 1249, 1254, 1324, 1678, 1696.
- a_make_name_string : 551, 560, 563.
- a_open_in : 27, 51, 563, 1451.
- a_open_out : 27, 560, 1619.
- A_token : 471.
- ab_vs_cd : 122, 127.
- abort : 586, 589, 590, 591, 594, 595, 596, 597, 598, 600, 602.
- above : 226, 1222, 1354, 1355, 1356.
- \above primitive : 1354.
- above_code : 1354, 1355, 1358, 1359.
- above_display_short_skip : 242, 988.
- \abovedisplayshortskip primitive : 244.
- above_display_short_skip_code : 242, 243, 244, 1379.
- above_display_skip : 242, 988.
- \abovedisplayskip primitive : 244.
- above_display_skip_code : 242, 243, 244, 1379, 1382.
- \abovewithdelims primitive : 1354.
- abs : 66, 125, 126, 127, 204, 229, 236, 237, 444, 448, 474, 527, 637, 686, 690, 692, 693, 705, 706, 837, 849, 892, 911, 931, 932, 933, 1005, 1010, 1023, 1033, 1119, 1123, 1204, 1205, 1232, 1252, 1254, 1256, 1259, 1269, 1286, 1296, 1303, 1325, 1419, 1420, 1558, 1559, 1561, 1622, 1678, 1787.
- absorbing : 327, 328, 361, 499, 1680.
- acc_kern : 173, 209, 1301.
- accent : 226, 287, 288, 1266, 1298, 1340, 1341.
- \accent primitive : 287.
- accent_chr : 861, 870, 912, 1341.
- accent_noad : 861, 864, 870, 872, 907, 935, 1341, 1362.
- accent_noad_size : 861, 872, 935, 1341.
- act_width : 1040, 1041, 1042, 1045, 1606.
- action procedure : 1204.
- active : 180, 993, 1003, 1017, 1028, 1034, 1035, 1037, 1038, 1039, 1047, 1048, 1049.
- active_base : 238, 240, 270, 271, 273, 284, 285, 375, 468, 532, 706, 1328, 1433, 1465, 1491, 1493.
- active_char : 225, 366, 532.
- active_glue : 1839, 1842, 1843, 1848, 1849, 1850.
- active_height : 1145, 1150, 1151.
- active_node_size : 1019, 1034, 1038, 1039, 1839, 1840.
- active_node_size_extended : 1839, 1840.
- active_node_size_normal : 993, 1840.
- active_short : 1839, 1842, 1843, 1848, 1849, 1850.
- active_width : 997, 998, 1003, 1013, 1017, 1035, 1038, 1040, 1041, 1042, 1045, 1145.
- actual_looseness : 1046, 1047, 1049.
- add_action_ref : 1534, 1601.
- add_char_shrink : 826, 1013, 1016, 1040, 1041, 1044, 1045.
- add_char_shrink_end : 1013.
- add_char_stretch : 826, 1013, 1016, 1040, 1041, 1044, 1045.
- add_char_stretch_end : 1013.
- add_delims_to : 369.
- add_disc_width_to_active_width : 1013, 1043.
- add_disc_width_to_break_width : 1013, 1014.
- add_glue_ref : 221, 224, 456, 976, 1055, 1171, 1276, 1405, 1601, 1730, 1779, 1817.
- add_kern_shrink : 1013, 1016, 1040, 1044, 1045.
- add_kern_shrink_end : 1013.
- add_kern_stretch : 1013, 1016, 1040, 1044, 1045.
- add_kern_stretch_end : 1013.
- add_or_sub : 1789, 1790.
- add_sa_ptr : 1816.
- add_sa_ref : 1397, 1400, 1818, 1834, 1836, 1837.
- add_token_ref : 221, 224, 345, 1154, 1187, 1191, 1397, 1403, 1601, 1634, 1824, 1825, 1826, 1827.
- additional : 814, 815, 831, 846.

- adj_demerits*: [254](#), [1010](#), [1033](#).
- `\adjdemerits` primitive: [256](#).
- adj_demerits_code*: [254](#), [255](#), [256](#).
- adjust*: [603](#).
- adjust_head*: [180](#), [1063](#), [1064](#), [1252](#), [1261](#), [1375](#), [1381](#).
- adjust_interword_glue*: [705](#), [1217](#).
- adjust_node*: [160](#), [166](#), [193](#), [201](#), [220](#), [224](#), [817](#), [823](#), [829](#), [904](#), [935](#), [1003](#), [1040](#), [1074](#), [1276](#).
- adjust_pre*: [160](#), [215](#), [829](#), [1276](#).
- adjust_ptr*: [160](#), [215](#), [220](#), [224](#), [829](#), [1276](#).
- adjust_space_factor*: [1209](#), [1213](#).
- adjust_tail*: [817](#), [818](#), [821](#), [823](#), [829](#), [970](#), [1063](#), [1064](#), [1252](#), [1261](#), [1375](#).
- adjusted_hbox_group*: [291](#), [1238](#), [1259](#), [1261](#), [1658](#), [1676](#).
- adv_char_width*: [690](#), [726](#).
- adv_past*: [1606](#).
- advance*: [227](#), [287](#), [288](#), [1386](#), [1411](#), [1412](#), [1414](#).
- `\advance` primitive: [287](#).
- advance_major_tail*: [1089](#), [1092](#).
- after*: [165](#), [210](#), [1372](#), [1725](#), [1736](#).
- after_assignment*: [226](#), [287](#), [288](#), [1444](#).
- `\afterassignment` primitive: [287](#).
- after_group*: [226](#), [287](#), [288](#), [1447](#).
- `\aftergroup` primitive: [287](#).
- after_math*: [1369](#), [1370](#).
- after_token*: [1442](#), [1443](#), [1444](#), [1445](#).
- aire*: [586](#), [587](#), [589](#), [603](#).
- align_error*: [1302](#), [1303](#).
- align_group*: [291](#), [942](#), [948](#), [965](#), [974](#), [1307](#), [1308](#), [1658](#), [1676](#).
- align_head*: [180](#), [944](#), [951](#).
- align_peek*: [947](#), [948](#), [959](#), [973](#), [1224](#), [1309](#).
- align_ptr*: [944](#), [945](#), [946](#).
- align_stack_node_size*: [944](#), [946](#).
- align_state*: [88](#), [331](#), [346](#), [347](#), [348](#), [353](#), [361](#), [364](#), [369](#), [379](#), [420](#), [421](#), [422](#), [429](#), [468](#), [501](#), [508](#), [509](#), [512](#), [944](#), [945](#), [946](#), [948](#), [951](#), [957](#), [958](#), [959](#), [962](#), [963](#), [965](#), [1245](#), [1270](#), [1302](#), [1303](#).
- aligning*: [327](#), [328](#), [361](#), [951](#), [963](#).
- alignment of rules with characters: [616](#).
- allocffnts*: [706](#), [715](#), [720](#).
- alpha*: [586](#), [597](#), [599](#).
- alpha_file*: [25](#), [27](#), [28](#), [31](#), [32](#), [50](#), [54](#), [326](#), [506](#), [551](#), [1520](#).
- alpha_token*: [464](#), [466](#).
- alt_rule*: [1548](#), [1549](#), [1550](#), [1554](#), [1563](#).
- alter_aux*: [1418](#), [1419](#).
- alter_box_dimen*: [1418](#), [1423](#).
- alter_integer*: [1418](#), [1422](#).
- alter_page_so_far*: [1418](#), [1421](#).
- alter_prev_graf*: [1418](#), [1420](#).
- Ambiguous...*: [1359](#).
- Ambler, Ole*: [1100](#).
- AmSTeX*: [1509](#).
- any_mode*: [1221](#), [1224](#), [1233](#), [1239](#), [1243](#), [1249](#), [1273](#), [1278](#), [1280](#), [1302](#), [1310](#), [1386](#), [1444](#), [1447](#), [1450](#), [1452](#), [1461](#), [1466](#), [1525](#).
- any_state_plus*: [366](#), [367](#), [369](#).
- app_display*: [1379](#), [1380](#), [1381](#), [1741](#).
- app_lc_hex*: [48](#).
- app_space*: [1205](#), [1219](#).
- append_bead*: [1634](#).
- append_char*: [42](#), [48](#), [52](#), [58](#), [198](#), [213](#), [279](#), [542](#), [551](#), [706](#), [712](#), [717](#), [719](#), [726](#), [727](#), [866](#), [869](#), [1114](#).
- append_charnode_to_t*: [1083](#), [1086](#).
- append_choices*: [1347](#), [1348](#).
- append_dest_name*: [698](#).
- append_discretionary*: [1292](#), [1293](#).
- append_glue*: [1233](#), [1236](#), [1254](#).
- append_italic_correction*: [1288](#), [1289](#).
- append_kern*: [1233](#), [1237](#).
- append_link*: [730](#), [783](#), [1629](#), [1632](#), [1633](#).
- append_list*: [160](#), [973](#), [1063](#), [1252](#).
- append_list_end*: [160](#).
- append_nl*: [686](#).
- append_normal_space*: [1205](#).
- append_penalty*: [1278](#), [1279](#).
- append_ptr*: [698](#), [700](#).
- append_thread*: [739](#), [1634](#).
- append_to_name*: [545](#), [549](#).
- append_to_vlist*: [853](#), [973](#), [1063](#), [1252](#), [1741](#).
- area_delimiter*: [539](#), [541](#), [542](#), [543](#).
- Argument of \x has...*: [421](#).
- arith_error*: [104](#), [105](#), [106](#), [107](#), [112](#), [114](#), [474](#), [479](#), [486](#), [689](#), [1412](#), [1779](#), [1780](#), [1787](#), [1843](#).
- Arithmetic overflow*: [1412](#), [1779](#).
- artificial_demerits*: [1004](#), [1025](#), [1028](#), [1029](#), [1030](#).
- ASCII code*: [17](#), [529](#).
- ASCII_code*: [18](#), [19](#), [20](#), [29](#), [30](#), [31](#), [38](#), [42](#), [54](#), [58](#), [60](#), [82](#), [314](#), [363](#), [415](#), [542](#), [545](#), [549](#), [866](#), [1067](#), [1087](#), [1096](#), [1118](#), [1125](#), [1128](#), [1134](#), [1135](#), [1621](#).
- assign_dimen*: [227](#), [266](#), [267](#), [439](#), [1386](#), [1400](#), [1404](#).
- assign_font_dimen*: [227](#), [287](#), [288](#), [439](#), [1386](#), [1429](#).
- assign_font_int*: [227](#), [439](#), [1386](#), [1429](#), [1430](#), [1431](#).
- assign_glue*: [227](#), [244](#), [245](#), [439](#), [956](#), [1386](#), [1400](#), [1404](#).
- assign_int*: [227](#), [256](#), [257](#), [439](#), [1386](#), [1398](#), [1400](#), [1404](#), [1413](#), [1654](#), [1698](#).
- assign_mu_glue*: [227](#), [244](#), [245](#), [439](#), [1386](#), [1398](#), [1400](#), [1404](#), [1413](#).

- assign_toks*: [227](#), [248](#), [249](#), [251](#), [345](#), [439](#), [441](#),
[1386](#), [1400](#), [1402](#), [1403](#), [1654](#).
- assign_trace*: [299](#), [300](#), [301](#).
- at*: [1434](#).
- \atop* primitive: [1354](#).
- atop_code*: [1354](#), [1355](#), [1358](#).
- \atopwithdelims* primitive: [1354](#).
- attach_fraction*: [474](#), [479](#), [480](#), [482](#).
- attach_sign*: [474](#), [475](#), [481](#).
- auto_breaking*: [997](#), [1036](#), [1037](#), [1040](#), [1042](#).
- auto_expand*: [705](#).
- auto_expand_font*: [705](#), [720](#).
- auto_expand_vf*: [712](#), [720](#).
- auto_kern*: [173](#), [209](#), [705](#).
- aux*: [230](#), [231](#), [234](#), [974](#), [986](#).
- aux_field*: [230](#), [231](#), [236](#), [949](#).
- aux_save*: [974](#), [986](#), [1382](#).
- avail*: [136](#), [138](#), [139](#), [140](#), [141](#), [182](#), [186](#), [1487](#), [1488](#).
- AVAIL list clobbered...: [186](#).
- avl_find_obj*: [1553](#).
- avl_put_obj*: [698](#).
- awful_bad*: [1007](#), [1008](#), [1009](#), [1010](#), [1028](#), [1048](#),
[1145](#), [1149](#), [1150](#), [1162](#), [1180](#), [1181](#), [1182](#).
- axis_height*: [874](#), [880](#), [910](#), [920](#), [921](#), [923](#), [936](#).
- b*: [388](#), [490](#), [491](#), [496](#), [524](#), [549](#), [586](#), [624](#), [853](#), [879](#),
[880](#), [883](#), [885](#), [889](#), [1004](#), [1145](#), [1169](#), [1374](#),
[1423](#), [1464](#), [1653](#), [1741](#), [1779](#).
- b_close*: [28](#), [586](#), [670](#), [712](#), [772](#), [794](#).
- b_make_name_string*: [551](#), [558](#), [684](#).
- b_open_in*: [27](#), [589](#).
- b_open_out*: [27](#), [558](#), [684](#).
- back_error*: [349](#), [399](#), [422](#), [429](#), [441](#), [468](#), [472](#), [502](#),
[505](#), [529](#), [604](#), [957](#), [1254](#), [1260](#), [1337](#), [1373](#),
[1383](#), [1388](#), [1762](#), [1766](#), [1781](#).
- back_input*: [286](#), [303](#), [347](#), [348](#), [349](#), [392](#), [393](#), [394](#),
[398](#), [401](#), [405](#), [421](#), [431](#), [433](#), [441](#), [469](#), [470](#), [474](#),
[478](#), [481](#), [487](#), [552](#), [962](#), [1206](#), [1223](#), [1230](#), [1240](#),
[1266](#), [1271](#), [1300](#), [1303](#), [1308](#), [1314](#), [1326](#), [1328](#),
[1329](#), [1391](#), [1397](#), [1402](#), [1445](#), [1620](#), [1781](#), [1782](#).
- back_list*: [345](#), [347](#), [359](#), [433](#), [1464](#).
- backed_up*: [329](#), [333](#), [334](#), [336](#), [345](#), [346](#), [347](#), [1201](#).
- background*: [997](#), [998](#), [1001](#), [1011](#), [1037](#), [1038](#),
[1840](#).
- backup_backup*: [388](#).
- backup_head*: [180](#), [388](#), [433](#).
- BAD: [315](#), [316](#).
- bad*: [13](#), [14](#), [129](#), [312](#), [548](#), [1425](#), [1510](#).
- Bad \patterns: [1136](#).
- Bad \prevgraf: [1420](#).
- Bad character code: [460](#).
- Bad delimiter code: [463](#).
- Bad dump length: [497](#).
- Bad file offset: [497](#).
- Bad flag...: [188](#).
- Bad interaction mode: [1693](#).
- Bad link...: [200](#).
- Bad match number: [497](#).
- Bad mathchar: [462](#).
- Bad number: [461](#).
- Bad register code: [459](#), [1808](#).
- Bad space factor: [1419](#).
- bad_fmt*: [1479](#), [1482](#), [1484](#), [1488](#), [1493](#), [1505](#).
- bad_pool*: [51](#), [52](#), [53](#).
- bad_tfm*: [586](#).
- bad_vf*: [710](#), [712](#), [714](#), [717](#), [719](#), [725](#).
- badness*: [108](#), [834](#), [841](#), [848](#), [852](#), [1002](#), [1026](#), [1027](#),
[1150](#), [1182](#), [1844](#), [1845](#).
- \badness primitive: [442](#).
- badness_code*: [442](#), [450](#).
- banner*: [2](#), [61](#), [562](#), [1475](#).
- base_line*: [647](#), [651](#), [652](#), [656](#), [729](#), [730](#), [733](#), [734](#),
[737](#), [1642](#), [1643](#), [1644](#).
- base_ptr*: [84](#), [85](#), [332](#), [333](#), [334](#), [335](#), [1307](#), [1771](#),
[1772](#), [1773](#).
- baseline_skip*: [242](#), [265](#), [853](#).
- \baselineskip primitive: [244](#).
- baseline_skip_code*: [167](#), [242](#), [243](#), [244](#), [853](#).
- batch_mode*: [73](#), [75](#), [86](#), [90](#), [92](#), [93](#), [561](#), [1438](#),
[1439](#), [1505](#), [1506](#), [1693](#).
- \batchmode primitive: [1438](#).
- bc*: [566](#), [567](#), [569](#), [571](#), [586](#), [591](#), [592](#), [596](#), [603](#), [706](#).
- bch_label*: [586](#), [600](#), [603](#).
- bchar*: [586](#), [600](#), [603](#), [1076](#), [1078](#), [1080](#), [1081](#),
[1083](#), [1086](#), [1088](#), [1091](#), [1092](#), [1207](#), [1209](#),
[1212](#), [1213](#), [1216](#).
- bchar_label*: [575](#), [578](#), [603](#), [705](#), [706](#), [1084](#), [1091](#),
[1209](#), [1216](#), [1498](#), [1499](#).
- be_careful*: [112](#), [113](#), [114](#).
- before*: [165](#), [210](#), [1372](#), [1707](#), [1709](#), [1715](#), [1725](#),
[1736](#).
- before_rejected_cur_p*: [997](#), [1037](#).
- begin**: [7](#), [8](#).
- begin_box*: [1249](#), [1255](#), [1260](#).
- begin_diagnostic*: [76](#), [263](#), [306](#), [321](#), [345](#), [426](#), [427](#),
[528](#), [535](#), [608](#), [666](#), [669](#), [750](#), [837](#), [849](#), [1000](#),
[1037](#), [1162](#), [1167](#), [1181](#), [1186](#), [1297](#), [1469](#), [1472](#),
[1659](#), [1674](#), [1688](#), [1820](#).
- begin_file_reading*: [78](#), [87](#), [350](#), [509](#), [563](#), [1752](#).
- begin_group*: [226](#), [287](#), [288](#), [1239](#).
- \beginingroup primitive: [287](#).
- begin_insert_or_adjust*: [1273](#), [1275](#).
- begin_L_code*: [165](#), [1698](#), [1699](#), [1731](#).
- begin_LR_type*: [165](#), [1704](#).
- begin_M*: [1256](#).

- begin_M_code*: [165](#), [1256](#), [1743](#).
begin_name: [538](#), [541](#), [552](#), [553](#), [557](#).
begin_pseudoprint: [338](#), [340](#), [341](#).
begin_R_code: [165](#), [1698](#), [1699](#).
begin_reflect: [1697](#).
begin_token_list: [345](#), [381](#), [384](#), [412](#), [416](#), [948](#),
[962](#), [963](#), [973](#), [1200](#), [1205](#), [1259](#), [1267](#), [1315](#),
[1321](#), [1343](#), [1615](#).
\beginL primitive: [1698](#).
Beginning to dump...: [1506](#).
\beginR primitive: [1698](#).
below_display_short_skip: [242](#).
\belowdisplayshortskip primitive: [244](#).
below_display_short_skip_code: [242](#), [243](#), [244](#), [1379](#).
below_display_skip: [242](#).
\belowdisplayskip primitive: [244](#).
below_display_skip_code: [242](#), [243](#), [244](#), [1379](#), [1382](#).
best_bet: [1046](#), [1048](#), [1049](#), [1051](#), [1052](#), [1850](#).
best_height_plus_depth: [1146](#), [1149](#), [1185](#), [1186](#).
best_ins_ptr: [1156](#), [1180](#), [1184](#), [1193](#), [1195](#), [1196](#).
best_line: [1046](#), [1048](#), [1049](#), [1051](#), [1063](#), [1065](#).
best_page_break: [1155](#), [1180](#), [1188](#), [1189](#).
best_pl_glue: [1839](#), [1847](#), [1848](#).
best_pl_line: [1007](#), [1019](#), [1029](#).
best_pl_short: [1839](#), [1847](#), [1848](#).
best_place: [1007](#), [1019](#), [1029](#), [1145](#), [1149](#), [1155](#).
best_size: [1155](#), [1180](#), [1192](#).
beta: [586](#), [597](#), [599](#).
bf: [720](#).
big_op_spacing1: [875](#), [925](#).
big_op_spacing2: [875](#), [925](#).
big_op_spacing3: [875](#), [925](#).
big_op_spacing4: [875](#), [925](#).
big_op_spacing5: [875](#), [925](#).
big_switch: [227](#), [254](#), [1169](#), [1204](#), [1205](#), [1206](#),
[1211](#), [1217](#).
BigEndian order: [566](#).
biggest_char: [275](#), [281](#).
billion: [653](#).
bin_noad: [856](#), [864](#), [870](#), [872](#), [902](#), [903](#), [935](#),
[1332](#), [1333](#).
bin_op_penalty: [254](#), [935](#).
\binoppenalty primitive: [256](#).
bin_op_penalty_code: [254](#), [255](#), [256](#).
blank_line: [263](#).
bool: [496](#), [497](#).
boolean: [27](#), [31](#), [37](#), [45](#), [46](#), [47](#), [76](#), [79](#), [96](#), [104](#),
[106](#), [107](#), [112](#), [114](#), [183](#), [185](#), [263](#), [274](#), [303](#), [333](#),
[383](#), [388](#), [389](#), [433](#), [439](#), [466](#), [474](#), [487](#), [496](#), [499](#),
[524](#), [542](#), [550](#), [553](#), [575](#), [586](#), [605](#), [619](#), [647](#), [657](#),
[680](#), [686](#), [687](#), [689](#), [691](#), [693](#), [696](#), [698](#), [701](#), [702](#),
[704](#), [705](#), [706](#), [720](#), [725](#), [729](#), [738](#), [749](#), [750](#), [793](#),
[805](#), [815](#), [819](#), [821](#), [880](#), [893](#), [900](#), [965](#), [989](#),
[997](#), [999](#), [1002](#), [1003](#), [1004](#), [1051](#), [1075](#), [1082](#),
[1125](#), [1135](#), [1143](#), [1164](#), [1187](#), [1207](#), [1227](#), [1230](#),
[1255](#), [1267](#), [1281](#), [1336](#), [1370](#), [1387](#), [1412](#), [1457](#),
[1479](#), [1511](#), [1520](#), [1535](#), [1548](#), [1553](#), [1625](#), [1637](#),
[1653](#), [1657](#), [1658](#), [1659](#), [1753](#), [1771](#), [1773](#), [1779](#),
[1790](#), [1794](#), [1796](#), [1816](#), [1822](#), [1839](#).
bop: [610](#), [612](#), [613](#), [615](#), [617](#), [619](#), [666](#), [668](#).
Bosshard, Hans Rudolf: [484](#).
bot: [572](#).
bot_mark: [408](#), [409](#), [1187](#), [1191](#), [1806](#), [1825](#).
\botmark primitive: [410](#).
bot_mark_code: [408](#), [410](#), [411](#), [1806](#).
\botmarks primitive: [1806](#).
bottom: [693](#).
bottom_level: [291](#), [294](#), [303](#), [1240](#), [1244](#), [1658](#),
[1676](#).
bottom_line: [333](#).
bowels: [619](#).
box: [248](#), [250](#), [1167](#), [1168](#), [1184](#), [1190](#), [1192](#), [1193](#),
[1196](#), [1198](#), [1203](#), [1817](#), [1818](#), [1836](#).
\box primitive: [1247](#).
box_base: [248](#), [250](#), [251](#), [273](#), [1253](#).
box_code: [1247](#), [1248](#), [1255](#), [1283](#), [1286](#), [1858](#).
box_context: [1251](#), [1252](#), [1253](#), [1254](#), [1255](#), [1259](#),
[1260](#).
box_end: [1251](#), [1255](#), [1260](#), [1262](#).
box_error: [1167](#), [1168](#), [1190](#), [1203](#).
box_flag: [1247](#), [1251](#), [1253](#), [1259](#), [1417](#), [1678](#).
box_lr: [153](#), [643](#), [1701](#), [1711](#), [1712](#), [1742](#).
box_max_depth: [265](#), [1262](#).
\boxmaxdepth primitive: [266](#).
box_max_depth_code: [265](#), [266](#).
box_node_size: [153](#), [154](#), [220](#), [224](#), [821](#), [842](#),
[889](#), [901](#), [925](#), [930](#), [1152](#), [1196](#), [1276](#), [1286](#),
[1377](#), [1730](#), [1742](#).
box_ref: [228](#), [250](#), [297](#), [1253](#).
box_there: [1155](#), [1162](#), [1175](#), [1176](#).
box_val: [1400](#), [1812](#), [1817](#), [1818](#), [1820](#), [1836](#).
box_val_limit: [1812](#), [1835](#).
\box255 is not void: [1190](#).
bp: [484](#).
bp: [690](#).
brain: [1204](#).
breadth_max: [199](#), [200](#), [216](#), [251](#), [254](#), [1003](#),
[1517](#), [1820](#).
break: [34](#).
break_in: [34](#).
break_node: [993](#), [1003](#), [1019](#), [1025](#), [1029](#), [1030](#),
[1037](#), [1038](#), [1051](#), [1052](#).
break_penalty: [226](#), [287](#), [288](#), [1278](#).
break_type: [1003](#), [1011](#), [1019](#), [1020](#), [1033](#).

- break_width*: [997](#), [998](#), [1011](#), [1012](#), [1013](#), [1015](#), [1016](#), [1017](#), [1018](#), [1053](#).
- breakpoint*: [1516](#).
- broken_ins*: [1156](#), [1161](#), [1185](#), [1196](#).
- broken_penalty*: [254](#), [1065](#).
- \brokenpenalty* primitive: [256](#).
- broken_penalty_code*: [254](#), [255](#), [256](#).
- broken_ptr*: [1156](#), [1185](#), [1196](#).
- buf_size*: [11](#), [30](#), [31](#), [35](#), [71](#), [129](#), [286](#), [337](#), [350](#), [353](#), [363](#), [385](#), [388](#), [400](#), [550](#), [556](#), [560](#), [1512](#), [1753](#), [1765](#).
- buffer*: [30](#), [31](#), [36](#), [37](#), [45](#), [71](#), [83](#), [87](#), [88](#), [278](#), [279](#), [280](#), [286](#), [324](#), [325](#), [337](#), [340](#), [353](#), [363](#), [365](#), [374](#), [376](#), [377](#), [378](#), [382](#), [384](#), [385](#), [388](#), [400](#), [509](#), [510](#), [549](#), [550](#), [556](#), [557](#), [560](#), [564](#), [1515](#), [1517](#), [1645](#), [1753](#), [1758](#), [1765](#).
- Buffer size exceeded: [35](#).
- build_choices*: [1349](#), [1350](#).
- build_discretionary*: [1294](#), [1295](#).
- build_page*: [974](#), [986](#), [1163](#), [1169](#), [1201](#), [1230](#), [1236](#), [1252](#), [1267](#), [1270](#), [1276](#), [1279](#), [1321](#), [1376](#).
- by*: [1412](#).
- byname*: [1553](#), [1562](#).
- bypass_eoln*: [31](#).
- byte*: [702](#).
- byte_file*: [25](#), [27](#), [28](#), [551](#), [558](#), [565](#), [680](#), [710](#), [772](#).
- b0*: [128](#), [131](#), [132](#), [151](#), [239](#), [275](#), [290](#), [571](#), [572](#), [576](#), [580](#), [582](#), [590](#), [629](#), [710](#), [712](#), [714](#), [857](#), [859](#), [1096](#), [1133](#), [1485](#), [1486](#), [1751](#), [1753](#).
- b1*: [128](#), [131](#), [132](#), [151](#), [239](#), [275](#), [290](#), [571](#), [572](#), [580](#), [582](#), [590](#), [629](#), [710](#), [712](#), [714](#), [857](#), [859](#), [1096](#), [1133](#), [1485](#), [1486](#), [1751](#), [1753](#).
- b2*: [128](#), [131](#), [132](#), [571](#), [572](#), [580](#), [582](#), [590](#), [629](#), [710](#), [712](#), [714](#), [857](#), [859](#), [1485](#), [1486](#), [1751](#), [1753](#).
- b3*: [128](#), [131](#), [132](#), [571](#), [572](#), [582](#), [590](#), [629](#), [710](#), [712](#), [714](#), [857](#), [859](#), [1485](#), [1486](#), [1751](#), [1753](#).
- c*: [47](#), [63](#), [82](#), [162](#), [286](#), [296](#), [314](#), [363](#), [491](#), [496](#), [542](#), [545](#), [549](#), [586](#), [604](#), [608](#), [609](#), [619](#), [705](#), [815](#), [866](#), [868](#), [880](#), [883](#), [885](#), [886](#), [912](#), [923](#), [1068](#), [1087](#), [1128](#), [1134](#), [1135](#), [1169](#), [1187](#), [1262](#), [1277](#), [1286](#), [1293](#), [1312](#), [1327](#), [1331](#), [1357](#), [1419](#), [1421](#), [1422](#), [1423](#), [1451](#), [1455](#), [1464](#), [1513](#), [1676](#), [1774](#).
- c_leaders*: [167](#), [208](#), [655](#), [664](#), [1247](#), [1248](#).
- \cleaders* primitive: [1247](#).
- c_loc*: [1087](#), [1091](#).
- cal_expand_ratio*: [821](#), [823](#), [826](#), [832](#), [838](#), [1064](#).
- cal_margin_kern_var*: [820](#).
- call*: [228](#), [241](#), [297](#), [318](#), [388](#), [406](#), [413](#), [421](#), [422](#), [504](#), [533](#), [1394](#), [1397](#), [1401](#), [1402](#), [1403](#), [1471](#), [1769](#).
- call_func*: [687](#), [690](#), [692](#), [712](#), [714](#), [1535](#).
- cancel_boundary*: [1205](#), [1207](#), [1208](#), [1209](#).
- cancel_glue*: [1743](#).
- cancel_glue_cont*: [1743](#).
- cancel_glue_cont_cont*: [1743](#).
- cancel_glue_end*: [1743](#).
- cancel_glue_end_end*: [1743](#).
- cannot \read*: [510](#).
- car_ret*: [225](#), [250](#), [364](#), [369](#), [951](#), [954](#), [955](#), [957](#), [958](#), [959](#), [962](#), [1302](#).
- carriage_return*: [22](#), [49](#), [225](#), [250](#), [258](#), [385](#).
- case_shift*: [226](#), [1461](#), [1462](#), [1463](#).
- cat*: [363](#), [376](#), [377](#), [378](#).
- cat_code*: [248](#), [250](#), [254](#), [284](#), [363](#), [365](#), [376](#), [377](#), [378](#), [1515](#).
- \catcode* primitive: [1406](#).
- cat_code_base*: [248](#), [250](#), [251](#), [253](#), [1406](#), [1407](#), [1409](#).
- cc*: [363](#), [374](#), [377](#), [712](#), [717](#), [718](#).
- cc*: [484](#).
- change_box*: [1152](#), [1255](#), [1286](#), [1546](#), [1818](#).
- change_if_limit*: [523](#), [524](#), [535](#).
- char*: [19](#), [26](#), [546](#), [560](#).
- \char* primitive: [287](#).
- char_base*: [576](#), [578](#), [580](#), [592](#), [596](#), [603](#), [705](#), [706](#), [1498](#), [1499](#).
- char_box*: [883](#), [884](#), [885](#), [912](#).
- \chardef* primitive: [1398](#).
- char_def_code*: [1398](#), [1399](#), [1400](#).
- char_depth*: [580](#), [673](#), [826](#), [882](#), [883](#), [886](#), [1668](#).
- char_depth_end*: [580](#).
- char_exists*: [580](#), [600](#), [603](#), [604](#), [609](#), [673](#), [705](#), [882](#), [896](#), [912](#), [914](#), [923](#), [929](#), [1211](#), [1766](#).
- char_given*: [226](#), [439](#), [1110](#), [1205](#), [1213](#), [1266](#), [1300](#), [1327](#), [1330](#), [1398](#), [1399](#), [1400](#).
- char_height*: [580](#), [673](#), [826](#), [882](#), [883](#), [886](#), [1301](#), [1668](#).
- char_height_end*: [580](#).
- char_info*: [569](#), [576](#), [580](#), [581](#), [583](#), [596](#), [600](#), [603](#), [604](#), [609](#), [648](#), [673](#), [690](#), [705](#), [717](#), [726](#), [731](#), [821](#), [826](#), [882](#), [883](#), [886](#), [888](#), [889](#), [896](#), [898](#), [912](#), [914](#), [923](#), [1015](#), [1016](#), [1040](#), [1041](#), [1044](#), [1045](#), [1084](#), [1211](#), [1212](#), [1214](#), [1216](#), [1289](#), [1299](#), [1301](#), [1323](#), [1668](#), [1721](#), [1766](#).
- char_info_end*: [580](#).
- char_info_word*: [567](#), [569](#), [570](#).
- char_italic*: [580](#), [883](#), [888](#), [923](#), [929](#), [1289](#), [1668](#).
- char_italic_end*: [580](#).
- char_kern*: [583](#), [821](#), [915](#), [927](#), [1084](#), [1216](#).
- char_kern_end*: [583](#).
- char_map_array*: [707](#).
- char_move*: [725](#), [726](#).
- char_node*: [152](#), [161](#), [163](#), [180](#), [194](#), [574](#), [619](#), [648](#), [821](#), [926](#), [1055](#), [1082](#), [1204](#), [1289](#), [1314](#).

- char_num*: [226](#), [287](#), [288](#), [1110](#), [1205](#), [1213](#), [1266](#), [1300](#), [1327](#), [1330](#).
- char_pw*: [821](#), [823](#).
- char_shrink*: [821](#), [1013](#).
- char_stretch*: [821](#), [1013](#).
- char_tag*: [580](#), [596](#), [604](#), [705](#), [821](#), [882](#), [884](#), [914](#), [915](#), [923](#), [926](#), [1084](#), [1214](#).
- char_used_array*: [707](#), [708](#).
- char_warning*: [608](#), [609](#), [726](#), [731](#), [896](#), [1211](#).
- char_width*: [580](#), [648](#), [673](#), [690](#), [717](#), [726](#), [731](#), [821](#), [826](#), [883](#), [888](#), [889](#), [914](#), [1015](#), [1016](#), [1040](#), [1041](#), [1044](#), [1045](#), [1299](#), [1301](#), [1323](#), [1668](#), [1721](#).
- char_width_end*: [580](#).
- character*: [152](#), [161](#), [162](#), [192](#), [194](#), [224](#), [609](#), [648](#), [674](#), [705](#), [731](#), [820](#), [821](#), [823](#), [826](#), [855](#), [856](#), [857](#), [861](#), [865](#), [883](#), [889](#), [896](#), [898](#), [923](#), [926](#), [927](#), [1015](#), [1016](#), [1040](#), [1041](#), [1044](#), [1045](#), [1071](#), [1072](#), [1073](#), [1078](#), [1082](#), [1083](#), [1085](#), [1086](#), [1207](#), [1209](#), [1210](#), [1211](#), [1212](#), [1213](#), [1216](#), [1289](#), [1299](#), [1301](#), [1323](#), [1327](#), [1331](#), [1341](#), [1721](#), [1730](#).
- character set dependencies: [23](#), [49](#).
- check sum: [53](#), [568](#), [615](#).
- check_byte_range*: [596](#), [600](#).
- check_dimensions*: [900](#), [901](#), [907](#), [928](#).
- check_effective_tail*: [1256](#), [1281](#).
- check_existence*: [600](#), [601](#).
- check_expand_pars*: [821](#), [1015](#), [1016](#), [1040](#), [1041](#), [1044](#), [1045](#).
- check_full_save_stack*: [295](#), [296](#), [298](#), [302](#), [1834](#).
- check_image_b*: [768](#).
- check_image_c*: [768](#).
- check_image_i*: [768](#).
- check_interrupt*: [96](#), [346](#), [365](#), [927](#), [1086](#), [1206](#), [1216](#).
- check_mem*: [183](#), [185](#), [1206](#), [1517](#).
- check_outer_validity*: [358](#), [373](#), [375](#), [376](#), [379](#), [384](#), [401](#).
- check_pdfoutput*: [1535](#), [1536](#), [1537](#), [1538](#), [1539](#), [1540](#), [1542](#), [1544](#), [1546](#), [1547](#), [1551](#), [1552](#), [1556](#), [1558](#), [1559](#), [1561](#), [1563](#), [1565](#), [1566](#), [1567](#), [1570](#), [1572](#), [1573](#), [1576](#), [1577](#), [1578](#), [1579](#), [1580](#), [1586](#), [1587](#), [1588](#), [1589](#), [1591](#), [1592](#), [1593](#), [1594](#), [1595](#), [1596](#).
- check_pdfversion*: [683](#), [698](#), [792](#), [1551](#).
- check_shrinkage*: [999](#), [1001](#), [1042](#).
- checkpdfrestore*: [727](#).
- checkpdfsave*: [727](#).
- Chinese characters: [152](#), [612](#).
- choice_node*: [862](#), [863](#), [864](#), [872](#), [904](#).
- choose_mlist*: [905](#).
- chr*: [19](#), [20](#), [23](#), [24](#), [1398](#).
- chr_cmd*: [320](#), [955](#).
- chr_code*: [245](#), [249](#), [257](#), [267](#), [288](#), [320](#), [403](#), [411](#), [437](#), [439](#), [443](#), [495](#), [514](#), [518](#), [955](#), [1159](#), [1229](#), [1235](#), [1247](#), [1248](#), [1265](#), [1284](#), [1291](#), [1319](#), [1333](#), [1346](#), [1355](#), [1365](#), [1385](#), [1396](#), [1399](#), [1407](#), [1427](#), [1431](#), [1437](#), [1439](#), [1449](#), [1454](#), [1463](#), [1465](#), [1468](#), [1471](#), [1524](#), [1684](#), [1690](#), [1695](#), [1699](#), [1745](#), [1768](#), [1829](#), [1830](#), [1858](#), [1859](#).
- clang*: [230](#), [231](#), [986](#), [1209](#), [1267](#), [1376](#), [1621](#), [1622](#).
- clean_box*: [894](#), [908](#), [909](#), [911](#), [912](#), [916](#), [918](#), [923](#), [924](#), [931](#), [932](#), [933](#).
- clear_for_error_prompt*: [78](#), [83](#), [352](#), [368](#).
- clear_terminal*: [34](#), [352](#), [556](#), [1516](#).
- CLOBBERED: [315](#).
- clobbered*: [185](#), [186](#), [187](#).
- close*: [28](#).
- close_files_and_terminate*: [78](#), [81](#), [1510](#), [1511](#).
- `\closein` primitive: [1448](#).
- close_noad*: [856](#), [864](#), [870](#), [872](#), [902](#), [935](#), [936](#), [1332](#), [1333](#).
- close_node*: [1519](#), [1522](#), [1524](#), [1526](#), [1600](#), [1601](#), [1602](#), [1617](#), [1619](#), [1620](#).
- `\closeout` primitive: [1522](#).
- closed*: [506](#), [507](#), [509](#), [511](#), [512](#), [527](#), [1451](#).
- clr*: [911](#), [917](#), [919](#), [920](#), [930](#), [931](#), [932](#), [933](#).
- `\clubpenalties` primitive: [1861](#).
- club_penalties_loc*: [248](#), [1861](#), [1862](#).
- club_penalties_ptr*: [1065](#), [1861](#).
- club_penalty*: [254](#), [1065](#).
- `\clubpenalty` primitive: [256](#).
- club_penalty_code*: [254](#), [255](#), [256](#).
- cm*: [484](#).
- cmd*: [320](#), [712](#), [715](#), [717](#), [719](#), [725](#), [726](#), [727](#), [1398](#), [1465](#), [1471](#), [1829](#).
- cmd_length*: [712](#), [714](#), [717](#), [719](#).
- co_backup*: [388](#).
- code*: [673](#).
- Color stack action is missing: [1537](#).
- colorspace*: [1550](#).
- colorstack_current*: [695](#), [727](#), [1537](#), [1600](#).
- colorstack_data*: [695](#), [1537](#), [1600](#), [1601](#), [1602](#).
- colorstack_pop*: [695](#), [727](#), [1537](#), [1600](#).
- colorstack_push*: [695](#), [727](#), [1537](#), [1600](#).
- colorstack_set*: [695](#), [727](#), [1537](#), [1600](#).
- colorstackcurrent*: [727](#).
- colorstackpop*: [727](#).
- colorstackpush*: [727](#).
- colorstackset*: [727](#).
- colorstackskippagestart*: [727](#).
- colorstackused*: [727](#), [1537](#).
- combine_two_deltas*: [1034](#).
- comment*: [225](#), [250](#), [369](#).

- common_ending*: [15](#), [524](#), [526](#), [535](#), [821](#), [834](#), [840](#),
[841](#), [842](#), [848](#), [851](#), [852](#), [1070](#), [1078](#), [1433](#), [1436](#),
[1469](#), [1470](#), [1473](#), [1709](#).
- compare_strings*: [497](#), [1535](#).
- Completed box...**: [666](#), [750](#).
- compress_trie*: [1124](#), [1127](#).
- concat_tokens*: [1575](#), [1576](#), [1577](#), [1578](#), [1579](#), [1580](#).
- cond_math_glue*: [167](#), [207](#), [906](#), [1347](#).
- cond_ptr*: [321](#), [350](#), [384](#), [515](#), [516](#), [521](#), [522](#),
[523](#), [524](#), [526](#), [535](#), [1513](#), [1665](#), [1688](#), [1770](#),
[1773](#), [1774](#).
- conditional*: [388](#), [391](#), [524](#).
- confusion*: [95](#), [112](#), [220](#), [224](#), [303](#), [523](#), [658](#), [693](#),
[727](#), [740](#), [829](#), [843](#), [902](#), [910](#), [928](#), [935](#), [940](#),
[965](#), [972](#), [974](#), [1015](#), [1016](#), [1040](#), [1044](#), [1045](#),
[1051](#), [1143](#), [1148](#), [1175](#), [1244](#), [1256](#), [1361](#),
[1376](#), [1387](#), [1526](#), [1600](#), [1601](#), [1602](#), [1617](#), [1634](#),
[1709](#), [1722](#), [1727](#), [1742](#).
- continental_point_token*: [464](#), [474](#).
- continue*: [15](#), [82](#), [83](#), [84](#), [88](#), [89](#), [415](#), [418](#), [419](#),
[420](#), [421](#), [423](#), [499](#), [500](#), [502](#), [725](#), [726](#), [749](#), [821](#),
[880](#), [882](#), [948](#), [958](#), [989](#), [1003](#), [1006](#), [1025](#), [1071](#),
[1081](#), [1084](#), [1085](#), [1086](#), [1169](#), [1176](#), [1779](#), [1780](#).
- contrib_head*: [180](#), [233](#), [236](#), [1163](#), [1169](#), [1170](#),
[1173](#), [1174](#), [1176](#), [1192](#), [1198](#), [1201](#).
- contrib_tail*: [1170](#), [1192](#), [1198](#), [1201](#).
- contribute*: [1169](#), [1172](#), [1175](#), [1177](#), [1183](#), [1608](#).
- conv_toks*: [388](#), [391](#), [496](#).
- conventions for representing stacks: [322](#).
- convert*: [228](#), [388](#), [391](#), [494](#), [495](#), [496](#), [1646](#).
- convert_to_break_width*: [1017](#).
- \copy** primitive: [1247](#).
- copy_code*: [1247](#), [1248](#), [1255](#), [1283](#), [1284](#), [1286](#),
[1856](#), [1858](#).
- copy_expand_params*: [705](#), [720](#).
- copy_font_info*: [706](#).
- copy_node_list*: [179](#), [221](#), [222](#), [224](#), [1255](#), [1286](#),
[1632](#), [1633](#), [1742](#).
- copy_to_cur_active*: [1003](#), [1035](#).
- count*: [254](#), [453](#), [666](#), [668](#), [750](#), [1161](#), [1183](#),
[1184](#), [1185](#).
- \count** primitive: [437](#).
- count_base*: [254](#), [257](#), [260](#), [1400](#), [1413](#).
- \countdef** primitive: [1398](#).
- count_def_code*: [1398](#), [1399](#), [1400](#).
- count_do_snap*: [1568](#), [1569](#), [1634](#).
- cp*: [820](#), [1003](#).
- cp_skipable*: [498](#), [1003](#).
- \cr** primitive: [954](#).
- cr_code*: [954](#), [955](#), [963](#), [965](#), [966](#).
- \cr cr** primitive: [954](#).
- cr_cr_code*: [954](#), [959](#), [963](#).
- cramped*: [862](#), [876](#).
- cramped_style*: [876](#), [908](#), [911](#), [912](#).
- creationdate_given*: [805](#).
- Creator*: [805](#).
- creator_given*: [805](#).
- cs*: [712](#).
- cs_count*: [274](#), [277](#), [279](#), [1494](#), [1495](#), [1512](#).
- cs_error*: [1310](#), [1311](#).
- cs_name*: [228](#), [287](#), [288](#), [388](#), [391](#).
- \csname** primitive: [287](#).
- cs_token_flag*: [286](#), [311](#), [312](#), [315](#), [356](#), [358](#), [359](#),
[361](#), [379](#), [380](#), [387](#), [393](#), [394](#), [395](#), [398](#), [401](#),
[405](#), [406](#), [407](#), [466](#), [468](#), [492](#), [532](#), [954](#), [1221](#),
[1241](#), [1308](#), [1391](#), [1465](#), [1490](#), [1615](#).
- cur_active_width*: [997](#), [998](#), [1003](#), [1006](#), [1011](#),
[1017](#), [1018](#), [1025](#), [1026](#), [1027](#), [1034](#), [1843](#),
[1844](#), [1845](#), [1846](#).
- cur_align*: [944](#), [945](#), [946](#), [951](#), [952](#), [953](#), [957](#), [960](#),
[962](#), [963](#), [965](#), [966](#), [969](#), [970](#), [972](#).
- cur_area*: [538](#), [543](#), [555](#), [556](#), [563](#), [772](#), [1433](#),
[1436](#), [1529](#), [1619](#).
- cur_boundary*: [292](#), [293](#), [294](#), [296](#), [304](#), [350](#), [384](#),
[1676](#), [1770](#), [1771](#), [1774](#).
- cur_box*: [1250](#), [1251](#), [1252](#), [1253](#), [1254](#), [1255](#), [1256](#),
[1257](#), [1258](#), [1260](#), [1262](#), [1263](#), [1836](#).
- cur_break*: [995](#), [1003](#), [1019](#), [1025](#), [1053](#), [1054](#),
[1055](#), [1704](#).
- cur_c*: [896](#), [897](#), [898](#), [912](#), [923](#), [926](#), [927](#), [929](#).
- cur_chr*: [88](#), [286](#), [318](#), [319](#), [321](#), [354](#), [359](#), [363](#), [365](#),
[370](#), [371](#), [373](#), [374](#), [375](#), [376](#), [377](#), [378](#), [379](#), [380](#),
[381](#), [382](#), [386](#), [387](#), [391](#), [394](#), [395](#), [404](#), [406](#), [407](#),
[412](#), [413](#), [415](#), [429](#), [433](#), [439](#), [450](#), [454](#), [468](#), [491](#),
[496](#), [498](#), [500](#), [502](#), [504](#), [505](#), [509](#), [520](#), [521](#), [524](#),
[526](#), [527](#), [532](#), [533](#), [534](#), [535](#), [536](#), [552](#), [604](#), [956](#),
[959](#), [963](#), [1110](#), [1112](#), [1137](#), [1205](#), [1209](#), [1211](#),
[1213](#), [1221](#), [1225](#), [1234](#), [1236](#), [1237](#), [1242](#), [1249](#),
[1255](#), [1259](#), [1266](#), [1268](#), [1269](#), [1277](#), [1281](#), [1282](#),
[1286](#), [1293](#), [1300](#), [1304](#), [1316](#), [1318](#), [1327](#), [1328](#),
[1330](#), [1331](#), [1334](#), [1335](#), [1336](#), [1347](#), [1357](#), [1367](#),
[1387](#), [1388](#), [1389](#), [1393](#), [1394](#), [1397](#), [1400](#), [1401](#),
[1402](#), [1403](#), [1404](#), [1408](#), [1409](#), [1410](#), [1413](#), [1419](#),
[1421](#), [1422](#), [1423](#), [1424](#), [1428](#), [1429](#), [1441](#), [1451](#),
[1455](#), [1464](#), [1469](#), [1513](#), [1526](#), [1528](#), [1620](#), [1671](#),
[1685](#), [1693](#), [1700](#), [1746](#), [1758](#), [1762](#), [1769](#), [1860](#).
- cur_cmd*: [88](#), [229](#), [286](#), [318](#), [319](#), [321](#), [354](#), [359](#),
[363](#), [364](#), [365](#), [366](#), [370](#), [371](#), [373](#), [375](#), [376](#), [379](#),
[380](#), [382](#), [386](#), [387](#), [388](#), [391](#), [392](#), [394](#), [395](#), [398](#),
[406](#), [407](#), [412](#), [413](#), [429](#), [430](#), [432](#), [433](#), [439](#),
[441](#), [454](#), [466](#), [468](#), [469](#), [470](#), [474](#), [478](#), [481](#),
[487](#), [489](#), [500](#), [503](#), [504](#), [505](#), [509](#), [520](#), [527](#),
[532](#), [533](#), [552](#), [604](#), [951](#), [956](#), [957](#), [958](#), [959](#),
[962](#), [963](#), [965](#), [1110](#), [1136](#), [1204](#), [1205](#), [1213](#),

- 1221, 1225, 1242, 1254, 1255, 1260, 1271, 1275, 1300, 1304, 1314, 1327, 1328, 1336, 1341, 1352, 1353, 1373, 1382, 1387, 1388, 1389, 1397, 1402, 1403, 1404, 1412, 1413, 1428, 1446, 1620, 1680, 1700, 1762, 1763, 1764, 1769, 1781.
- cur_cs*: [319](#), 354, 355, 358, 359, 360, 363, 373, 375, 376, 378, 379, 380, 387, 394, 395, 398, 400, 405, 406, 407, 415, 417, 433, 498, 499, 527, 533, 706, 948, 1221, 1328, 1391, 1394, 1397, 1400, 1401, 1402, 1433, 1470, 1530, 1535, 1615, 1680, 1764, 1765.
- cur_delta_h*: [691](#).
- cur_dir*: [643](#), [651](#), [654](#), [656](#), [660](#), [661](#), [665](#), [733](#), [736](#), [737](#), [742](#), [743](#), [746](#), [1702](#), 1703, 1711, 1712, 1714, 1717, 1719, 1725, 1727, 1731, 1732, 1733, 1734, 1735, 1736.
- cur_ext*: [538](#), 543, 555, 556, 563, 772, 1451, 1529, 1619.
- cur_f*: [896](#), [898](#), 912, 915, 923, 926, 927, 929.
- cur_fam*: [254](#), 1327, 1331, 1341.
- cur_fam_code*: [254](#), 255, 256, 1315, 1321.
- cur_file*: [326](#), 351, 384, 563, 564, 1752.
- cur_font*: [248](#), 250, 584, 585, 604, 1207, 1209, 1218, 1220, 1293, 1299, 1300, 1731.
- cur_font_loc*: [248](#), 250, 251, 252, 1393.
- cur_font_step*: [821](#), [997](#), 1001, 1025.
- cur_g*: [647](#), 653, [657](#), 662, [729](#), 735, [738](#), 744, 1634, 1635, 1696, 1718, 1719, [1720](#).
- cur_glue*: [647](#), 653, [657](#), 662, [729](#), 735, [738](#), 744, 1634, 1635, 1696, 1718, 1719, [1720](#).
- cur_group*: 292, [293](#), 294, 296, 303, 304, 974, 1238, 1239, 1240, 1241, 1243, 1244, 1245, 1306, 1307, 1316, 1318, 1367, 1368, 1369, 1370, 1376, 1658, 1662, 1676, 1774.
- cur_h*: [643](#), 645, 646, 647, 648, 650, 651, 654, 655, 656, 657, 660, 661, 665, 691, 692, 693, 725, 726, 727, 729, 731, 732, 733, 734, 736, 737, 738, 742, 743, 746, 752, 1618, 1627, 1632, 1634, 1638, 1639, 1640, 1641, 1643, 1644, 1711, 1713, 1716, 1717, 1718, 1719, 1721, 1722, 1726.
- cur_h_offset*: 644, 752, 755, [1625](#).
- cur_head*: [944](#), 945, 946, 960, 973.
- cur_height*: [1145](#), 1147, 1148, 1149, 1150, 1151, 1609.
- cur_i*: [896](#), [897](#), [898](#), 912, 915, 923, 926, 927, 929.
- cur_if*: 321, 358, [515](#), 516, 521, 522, 1513, 1665, 1688, 1773, 1774.
- cur_indent*: [1051](#), 1064.
- cur_input*: 35, 36, 87, [323](#), 324, 333, 343, 344, 560, 1307, 1771, 1773.
- cur_l*: [1082](#), 1083, 1084, 1085, 1086, 1207, 1209, 1210, 1211, 1212, 1214, 1216.
- cur_lang*: 1066, [1067](#), 1098, 1099, 1105, 1109, 1114, 1119, 1138, 1267, 1376, 1606, 1607, 1852, 1855.
- cur_length*: [41](#), 198, 200, 279, 281, 542, 551, 645, 727, 866, 1612.
- cur_level*: 292, [293](#), 294, 296, 299, 300, 302, 303, 1480, 1513, 1658, 1662, 1676, 1774, 1834, 1836.
- cur_line*: [1051](#), 1063, 1064, 1065.
- cur_list*: [231](#), 234, 235, 236, 448, 1420, 1676.
- cur_loop*: [944](#), 945, 946, 951, 957, 966, 967, 968.
- cur_mark*: 318, [408](#), 412, 1513, 1806.
- cur_mlist*: [893](#), 894, 900, 928, 1370, 1372, 1375.
- cur_mu*: [877](#), [893](#), 904, 906, 940.
- cur_name*: [538](#), 543, 555, 556, 563, 772, 1433, 1434, 1436, 1529, 1619.
- cur_order*: 388, 465, [473](#), 474, 480, 488.
- cur_p*: 997, [1002](#), 1003, 1004, 1007, 1011, 1013, 1014, 1019, 1025, 1026, 1027, 1029, 1030, 1031, 1032, 1033, 1034, 1036, 1037, 1039, 1040, 1041, 1042, 1043, 1046, 1051, 1052, 1053, 1054, 1055, 1069, 1078, 1606, 1704, 1846, 1849.
- cur_page_height*: 644, 693, 727, 752, 755, 769, 780, 1618, [1625](#), 1627, 1632, 1638.
- cur_page_width*: 644, 755, 769, [1625](#).
- cur_pos*: 1634.
- cur_pre_head*: [944](#), 945, 946, 960, 973.
- cur_pre_tail*: [944](#), 945, 946, 960, 970, 973.
- cur_ptr*: 412, 441, 453, 1400, 1402, 1403, 1413, 1812, [1813](#), 1816, 1817, 1818, 1821, 1822, 1824, 1827, 1828, 1836.
- cur_q*: [1082](#), 1083, 1085, 1086, 1209, 1210, 1211, 1212, 1216.
- cur_r*: [1082](#), 1083, 1084, 1085, 1086, 1207, 1209, 1212, 1213, 1214, 1216.
- cur_rh*: [1081](#), 1083, 1084, 1085.
- cur_s*: 620, [643](#), 647, 657, 668, 670, 729, 730, 738, 739, 751, 1632, 1634.
- cur_size*: 874, 875, 877, [893](#), 896, 897, 906, 910, 911, 918, 920, 921, 922, 923, 931, 932, 933, 936.
- cur_span*: [944](#), 945, 946, 961, 970, 972.
- cur_style*: [877](#), [893](#), 894, 900, 901, 904, 905, 908, 909, 911, 912, 916, 918, 919, 920, 922, 923, 924, 928, 930, 931, 932, 933, 934, 936, 937, 940, 1370, 1372, 1375.
- cur_tail*: [944](#), 945, 946, 960, 970, 973.
- cur_tok*: 88, 286, 303, [319](#), 347, 348, 349, 358, 386, 387, 388, 392, 393, 394, 395, 398, 401, 405, 406, 407, 418, 419, 420, 421, 423, 425, 429, 431, 433, 466, 467, 468, 470, 471, 474, 478, 500, 502, 503, 505, 509, 520, 529, 532, 957, 958, 1213, 1221, 1223, 1271, 1303, 1304, 1308, 1391, 1397, 1444, 1445, 1447, 1615, 1616, 1680, 1758, 1764, 1766, 1769, 1781, 1782.

- cur_v*: [643](#), [646](#), [647](#), [651](#), [652](#), [656](#), [657](#), [659](#), [660](#),
[661](#), [663](#), [664](#), [665](#), [668](#), [692](#), [693](#), [725](#), [726](#),
[727](#), [729](#), [733](#), [734](#), [737](#), [738](#), [741](#), [742](#), [743](#),
[745](#), [746](#), [752](#), [1618](#), [1627](#), [1634](#), [1638](#), [1639](#),
[1640](#), [1641](#), [1643](#), [1644](#).
cur_v_offset: [644](#), [752](#), [755](#), [1625](#).
cur_val: [286](#), [287](#), [356](#), [388](#), [412](#), [436](#), [439](#), [440](#),
[441](#), [445](#), [446](#), [447](#), [449](#), [450](#), [451](#), [452](#), [453](#), [455](#),
[456](#), [457](#), [459](#), [460](#), [461](#), [462](#), [463](#), [464](#), [465](#), [466](#),
[468](#), [470](#), [471](#), [473](#), [474](#), [476](#), [477](#), [479](#), [481](#), [483](#),
[484](#), [486](#), [487](#), [488](#), [489](#), [491](#), [492](#), [497](#), [498](#), [508](#),
[517](#), [527](#), [529](#), [530](#), [535](#), [579](#), [604](#), [605](#), [606](#), [607](#),
[693](#), [705](#), [706](#), [720](#), [815](#), [954](#), [956](#), [1110](#), [1152](#),
[1205](#), [1213](#), [1236](#), [1237](#), [1249](#), [1253](#), [1258](#), [1275](#),
[1277](#), [1279](#), [1299](#), [1300](#), [1327](#), [1330](#), [1336](#), [1337](#),
[1341](#), [1358](#), [1364](#), [1400](#), [1401](#), [1402](#), [1403](#), [1404](#),
[1405](#), [1408](#), [1410](#), [1412](#), [1413](#), [1414](#), [1415](#), [1416](#),
[1417](#), [1419](#), [1420](#), [1421](#), [1422](#), [1423](#), [1424](#), [1429](#),
[1434](#), [1435](#), [1451](#), [1472](#), [1522](#), [1528](#), [1535](#), [1537](#),
[1542](#), [1544](#), [1547](#), [1550](#), [1552](#), [1554](#), [1556](#), [1561](#),
[1563](#), [1564](#), [1571](#), [1573](#), [1583](#), [1585](#), [1587](#), [1591](#),
[1622](#), [1648](#), [1662](#), [1665](#), [1668](#), [1671](#), [1680](#), [1685](#),
[1691](#), [1693](#), [1766](#), [1777](#), [1779](#), [1782](#), [1800](#), [1801](#),
[1808](#), [1816](#), [1817](#), [1818](#), [1821](#), [1836](#), [1863](#).
cur_val_level: [388](#), [436](#), [439](#), [441](#), [445](#), [446](#), [447](#),
[449](#), [450](#), [453](#), [455](#), [456](#), [465](#), [475](#), [477](#), [481](#), [487](#),
[491](#), [492](#), [497](#), [1535](#), [1671](#), [1777](#), [1779](#).
cur_width: [1051](#), [1064](#).
current page: [1155](#).
current_character_being_worked_on: [596](#).
\currentgrouplevel primitive: [1660](#).
current_group_level_code: [1660](#), [1661](#), [1662](#).
\currentgrouptype primitive: [1660](#).
current_group_type_code: [1660](#), [1661](#), [1662](#).
\currentifbranch primitive: [1663](#).
current_if_branch_code: [1663](#), [1664](#), [1665](#).
\currentiflevel primitive: [1663](#).
current_if_level_code: [1663](#), [1664](#), [1665](#).
\currentiftype primitive: [1663](#).
current_if_type_code: [1663](#), [1664](#), [1665](#).
cv_backup: [388](#).
cvl_backup: [388](#).
c1: [793](#).
c2: [793](#).
d: [107](#), [194](#), [195](#), [278](#), [363](#), [466](#), [586](#), [689](#), [821](#), [842](#),
[853](#), [880](#), [989](#), [1004](#), [1051](#), [1119](#), [1145](#), [1244](#),
[1262](#), [1314](#), [1374](#), [1680](#), [1741](#), [1794](#), [1796](#).
d_fixed: [635](#), [636](#).
danger: [1370](#), [1371](#), [1375](#).
data: [228](#), [250](#), [1393](#), [1408](#), [1410](#).
data structure assumptions: [179](#), [182](#), [222](#), [643](#),
[990](#), [1143](#), [1156](#), [1465](#), [1730](#).
day: [254](#), [259](#), [645](#), [792](#), [1506](#).
\day primitive: [256](#).
day_code: [254](#), [255](#), [256](#).
dd: [484](#).
dd: [689](#).
deactivate: [1003](#), [1025](#), [1028](#).
dead_cycles: [445](#), [619](#), [620](#), [666](#), [750](#), [1187](#), [1199](#),
[1200](#), [1230](#), [1418](#), [1422](#).
\deadcycles primitive: [442](#).
debug: [7](#), [9](#), [78](#), [84](#), [93](#), [132](#), [183](#), [184](#), [185](#),
[190](#), [1206](#), [1516](#).
debug #: [1516](#).
debug_help: [78](#), [84](#), [93](#), [1516](#).
debugging: [7](#), [84](#), [96](#), [132](#), [183](#), [200](#), [1206](#), [1516](#).
decent_fit: [991](#), [1008](#), [1026](#), [1027](#), [1038](#), [1844](#), [1845](#).
decr: [16](#), [42](#), [44](#), [64](#), [71](#), [86](#), [88](#), [89](#), [90](#), [92](#), [102](#),
[124](#), [138](#), [139](#), [141](#), [193](#), [195](#), [218](#), [219](#), [223](#), [235](#),
[263](#), [279](#), [282](#), [303](#), [304](#), [333](#), [344](#), [346](#), [347](#), [348](#),
[351](#), [353](#), [369](#), [378](#), [379](#), [382](#), [384](#), [420](#), [425](#), [448](#),
[455](#), [468](#), [496](#), [503](#), [509](#), [520](#), [535](#), [560](#), [564](#), [594](#),
[603](#), [628](#), [647](#), [657](#), [666](#), [670](#), [671](#), [674](#), [686](#), [690](#),
[698](#), [702](#), [712](#), [717](#), [719](#), [725](#), [726](#), [729](#), [738](#), [750](#),
[793](#), [890](#), [891](#), [977](#), [982](#), [1003](#), [1014](#), [1032](#), [1043](#),
[1057](#), [1090](#), [1091](#), [1105](#), [1106](#), [1115](#), [1119](#), [1123](#),
[1140](#), [1236](#), [1296](#), [1303](#), [1307](#), [1350](#), [1362](#), [1370](#),
[1420](#), [1469](#), [1487](#), [1513](#), [1515](#), [1534](#), [1632](#), [1676](#),
[1680](#), [1688](#), [1725](#), [1730](#), [1736](#), [1751](#), [1753](#), [1771](#),
[1772](#), [1773](#), [1774](#), [1777](#), [1779](#), [1816](#), [1818](#).
def: [227](#), [1384](#), [1385](#), [1386](#), [1389](#), [1394](#).
\def primitive: [1384](#).
def_code: [227](#), [439](#), [1386](#), [1406](#), [1407](#), [1408](#).
def_family: [227](#), [439](#), [604](#), [1386](#), [1406](#), [1407](#), [1410](#).
def_font: [227](#), [287](#), [288](#), [439](#), [604](#), [1386](#), [1432](#).
def_ref: [327](#), [328](#), [496](#), [497](#), [499](#), [508](#), [1135](#), [1277](#),
[1394](#), [1402](#), [1455](#), [1464](#), [1530](#), [1532](#), [1535](#), [1536](#),
[1537](#), [1538](#), [1542](#), [1546](#), [1550](#), [1554](#), [1556](#), [1561](#),
[1563](#), [1564](#), [1576](#), [1577](#), [1578](#), [1579](#), [1580](#), [1585](#),
[1587](#), [1588](#), [1589](#), [1614](#), [1680](#).
def_tounicode: [1585](#).
default_code: [857](#), [871](#), [917](#), [1358](#).
default_hyphen_char: [254](#), [603](#).
\defaultthyphenchar primitive: [256](#).
default_hyphen_char_code: [254](#), [255](#), [256](#).
default_res: [1550](#).
default_rule: [489](#).
default_rule_thickness: [857](#), [875](#), [908](#), [909](#), [911](#),
[917](#), [919](#), [933](#).
default_skew_char: [254](#), [603](#).
\defaultskewchar primitive: [256](#).
default_skew_char_code: [254](#), [255](#), [256](#).
defecation: [624](#).

define: 706, 1253, [1390](#), 1393, 1394, 1397, 1400, 1401, 1404, 1408, 1410, 1424, 1433, 1836.
defining: [327](#), 328, 361, 499, 508.
del_code: [254](#), 258, 1336.
\delcode primitive: [1406](#).
del_code_base: [254](#), 258, 260, 1406, 1408, 1409.
delete_action_ref: [1534](#), 1561, 1577, 1602.
delete_glue_ref: [219](#), 220, 297, 477, 491, 605, 705, 906, 976, 990, 1000, 1055, 1151, 1171, 1179, 1192, 1197, 1276, 1405, 1412, 1415, 1513, 1602, 1777, 1779, 1787, 1788, 1791, 1800, 1801, 1818, 1835, 1850.
delete_image: 778.
delete_last: 1280, [1281](#).
delete_q: [900](#), 934, 937.
delete_sa_ptr: [1816](#), 1818, 1822.
delete_sa_ref: [1818](#), 1831, 1836, 1837, 1838.
delete_token_ref: [218](#), 220, 297, 346, 497, 764, 1152, 1154, 1187, 1191, 1513, 1534, 1535, 1550, 1561, 1585, 1588, 1589, 1602, 1634, 1823, 1824, 1825, 1827, 1828, 1835.
delete_toks: 756, 763, [764](#), 772, 778, 789, 802, 804, 805, 812, 813.
deletions_allowed: [76](#), 77, 84, 85, 98, 358, 368.
delim_num: [225](#), 287, 288, 1222, 1327, 1330, 1336.
delim_ptr: [230](#), [231](#), 1361, 1367.
delimited_code: [1354](#), 1355, 1358, 1359.
delimiter: [861](#), 870, 936, 1367.
\delimiter primitive: [287](#).
delimiter_factor: [254](#), 936.
\delimiterfactor primitive: [256](#).
delimiter_factor_code: [254](#), 255, 256.
delimiter_shortfall: [265](#), 936.
\delimitershortfall primitive: [266](#).
delimiter_shortfall_code: [265](#), 266.
delim1: [874](#), 922.
delim2: [874](#), 922.
delta: [103](#), [900](#), 902, 907, [909](#), [910](#), [911](#), [912](#), 916, [917](#), 919, 920, 921, 922, [923](#), 924, 928, 929, [930](#), 933, [936](#), [1169](#), 1183, 1185, [1299](#), 1301.
delta_node: [996](#), 1004, 1006, 1017, 1018, 1034, 1035, 1039, 1048, 1049.
delta_node_size: [996](#), 1017, 1018, 1034, 1035, 1039.
delta1: [917](#), 920, [936](#).
delta2: [917](#), 920, [936](#).
den: [612](#), [614](#), 617.
denom: [476](#), 484.
denom_style: [876](#), 918.
denominator: [857](#), 864, 871, 872, 918, 1357, 1361.
denom1: [874](#), 918.
denom2: [874](#), 918.
deplorable: [1149](#), 1180.

depth: 489.
depth: [153](#), 154, 156, 157, 158, 202, 205, 206, 489, 580, 644, 650, 652, 654, 659, 660, 663, 669, 732, 734, 736, 741, 742, 745, 752, 755, 821, 825, 830, 842, 844, 853, 862, 878, 880, 883, 887, 901, 904, 905, 909, 910, 911, 919, 920, 921, 923, 924, 925, 930, 932, 933, 942, 943, 975, 980, 984, 1003, 1063, 1148, 1177, 1184, 1185, 1196, 1263, 1276, 1546, 1550, 1554, 1563, 1627, 1634, 1716, 1742.
depth_base: [576](#), 578, 580, 592, 598, 705, 706, 1498, 1499.
depth_index: [569](#), 580.
depth_offset: [153](#), 442, 943, 1423.
depth_threshold: [199](#), 200, 216, 251, 254, 866, 1003, 1517, 1820.
dest_name_entry: 698, 793, 1624, 1625.
dest_names: 697, 698, 793, 802, 803, [1625](#).
dest_names_size: 697, 698, 1511, [1625](#).
destroy_marks: 1513, [1822](#), 1828.
dests: 802, 1511.
destrysz: 695.
\detokenize primitive: [1683](#).
dig: [54](#), 64, 65, 67, 102, 478, 686, 702.
digit_sensed: [1135](#), 1136, 1137.
\dimexpr primitive: [1775](#).
dimen: [265](#), 453, 1183, 1185.
\dimen primitive: [437](#).
dimen_base: 238, [254](#), 265, 266, 267, 268, 269, 270, 1246, 1321.
\dimendef primitive: [1398](#).
dimen_def_code: [1398](#), 1399, 1400.
dimen_par: [265](#), 673.
dimen_pars: [265](#).
dimen_val: [436](#), [437](#), 439, 441, 442, 443, 444, 446, 447, 450, 451, 453, 454, 455, 475, 481, 491, 1413, 1671, 1775, 1776, 1782, 1787, 1789, 1792, 1795, 1812, 1817, 1820, 1829.
dimen_val_limit: [1812](#), 1818, 1819, 1834, 1838.
Dimension too large: 486.
direct_always: 497, 693, [695](#), 1536, 1600.
direct_page: 497, 693, [695](#), 1536, 1600.
dirty Pascal: [3](#), 132, 190, 200, 204, 307, 986, 1509.
disc_break: [1051](#), 1054, 1055, 1056, 1065.
disc_group: [291](#), 1293, 1294, 1295, 1658, 1676.
disc_node: [163](#), 166, 193, 201, 220, 224, 674, 821, 823, 904, 935, 991, 993, 1003, 1030, 1032, 1040, 1055, 1089, 1256.
disc_ptr: 1513, [1856](#), 1860.
disc_width: [1013](#), 1044.
discard_or_move: [1143](#).
discretionary: [226](#), [1266](#), 1290, 1291, 1292.
Discretionary list is too long: 1296.

- `\discretionary` primitive: [1290](#).
- `Display math...with $:` [1373](#).
- `display_indent:` [265](#), [974](#), [1314](#), [1321](#), [1375](#), [1741](#).
- `\displayindent` primitive: [266](#).
- `display_indent_code:` [265](#), [266](#), [1321](#).
- `\displaylimits` primitive: [1332](#).
- `display_mlist:` [863](#), [869](#), [872](#), [905](#), [1350](#).
- `display_style:` [862](#), [868](#), [905](#), [1345](#), [1375](#).
- `\displaystyle` primitive: [1345](#).
- `\displaywidowpenalties` primitive: [1861](#).
- `display_widow_penalties_loc:` [248](#), [1861](#), [1862](#).
- `display_widow_penalties_ptr:` [1065](#), [1861](#).
- `display_widow_penalty:` [254](#), [988](#), [1065](#).
- `\displaywidowpenalty` primitive: [256](#).
- `display_widow_penalty_code:` [254](#), [255](#), [256](#).
- `display_width:` [265](#), [1314](#), [1321](#), [1375](#), [1741](#).
- `\displaywidth` primitive: [266](#).
- `display_width_code:` [265](#), [266](#), [1321](#).
- `div:` [100](#), [655](#), [664](#).
- `divide:` [227](#), [287](#), [288](#), [1386](#), [1411](#), [1412](#).
- `\divide` primitive: [287](#).
- `divide_scaled:` [687](#), [689](#), [690](#), [692](#), [693](#), [792](#), [832](#), [838](#).
- `dlist:` [643](#), [981](#), [1370](#), [1378](#), [1701](#), [1711](#), [1712](#), [1742](#).
- `do_all_eight:` [997](#), [1003](#), [1006](#), [1011](#), [1017](#), [1018](#), [1034](#), [1035](#), [1038](#).
- `do_all_six:` [997](#), [1145](#), [1162](#).
- `do_annot:` [1627](#), [1636](#), [1642](#).
- `do_assignments:` [974](#), [1299](#), [1382](#), [1446](#).
- `do_char:` [710](#), [725](#), [726](#).
- `do_dest:` [1634](#), [1636](#), [1642](#).
- `do_endv:` [1306](#), [1307](#).
- `do_extension:` [1525](#), [1526](#), [1620](#).
- `do_last_line_fit:` [1019](#), [1020](#), [1025](#), [1026](#), [1029](#), [1037](#), [1038](#), [1839](#), [1840](#), [1850](#).
- `do_link:` [1558](#), [1632](#), [1642](#).
- `do_marks:` [1152](#), [1187](#), [1513](#), [1822](#).
- `do_nothing:` [16](#), [34](#), [57](#), [58](#), [84](#), [193](#), [220](#), [297](#), [366](#), [379](#), [497](#), [564](#), [595](#), [636](#), [638](#), [639](#), [650](#), [659](#), [687](#), [732](#), [741](#), [793](#), [823](#), [843](#), [866](#), [902](#), [907](#), [935](#), [1011](#), [1040](#), [1074](#), [1221](#), [1412](#), [1550](#), [1600](#), [1617](#), [1634](#), [1642](#).
- `do_one_seven_eight:` [997](#), [1014](#), [1043](#).
- `do_pdf_font:` [799](#).
- `do_register_command:` [1411](#), [1412](#).
- `do_seven_eight:` [997](#).
- `do_snapv:` [1634](#), [1636](#).
- `do_snapv_comp:` [1634](#), [1636](#).
- `do_subst_font:` [820](#), [821](#), [823](#), [826](#).
- `do_thread:` [1634](#), [1636](#), [1642](#).
- `do_vf:` [712](#), [720](#), [726](#).
- `do_vf_packet:` [721](#), [725](#), [726](#).
- `doing_leaders:` [619](#), [620](#), [656](#), [665](#), [737](#), [746](#), [1619](#), [1627](#), [1634](#).
- `done:` [15](#), [47](#), [53](#), [220](#), [303](#), [304](#), [333](#), [406](#), [415](#), [423](#), [466](#), [471](#), [474](#), [479](#), [484](#), [499](#), [500](#), [502](#), [508](#), [509](#), [520](#), [552](#), [556](#), [557](#), [563](#), [586](#), [593](#), [603](#), [642](#), [666](#), [668](#), [669](#), [698](#), [702](#), [706](#), [750](#), [751](#), [800](#), [872](#), [900](#), [912](#), [914](#), [934](#), [935](#), [948](#), [951](#), [989](#), [1003](#), [1011](#), [1037](#), [1047](#), [1051](#), [1055](#), [1070](#), [1081](#), [1084](#), [1086](#), [1106](#), [1135](#), [1136](#), [1145](#), [1149](#), [1152](#), [1154](#), [1169](#), [1172](#), [1173](#), [1180](#), [1255](#), [1256](#), [1257](#), [1286](#), [1295](#), [1297](#), [1314](#), [1322](#), [1387](#), [1403](#), [1428](#), [1511](#), [1535](#), [1602](#), [1676](#), [1720](#), [1726](#), [1733](#), [1734](#), [1735](#), [1758](#), [1796](#), [1860](#).
- `done_with_noad:` [900](#), [901](#), [902](#), [907](#), [928](#).
- `done_with_node:` [900](#), [901](#), [904](#), [905](#), [928](#).
- `done1:` [15](#), [185](#), [186](#), [415](#), [425](#), [474](#), [478](#), [499](#), [500](#), [750](#), [802](#), [912](#), [915](#), [948](#), [957](#), [989](#), [1003](#), [1026](#), [1051](#), [1053](#), [1069](#), [1071](#), [1074](#), [1135](#), [1140](#), [1169](#), [1172](#), [1175](#), [1478](#), [1491](#), [1511](#).
- `done2:` [15](#), [185](#), [187](#), [474](#), [484](#), [485](#), [499](#), [504](#), [948](#), [958](#), [989](#), [1071](#), [1478](#), [1492](#).
- `done3:` [15](#), [989](#), [1072](#), [1073](#).
- `done4:` [15](#), [989](#), [1074](#).
- `done5:` [15](#), [989](#), [1040](#), [1043](#).
- `done6:` [15](#).
- `dont_expand:` [228](#), [277](#), [379](#), [393](#).
- `double:` [111](#), [113](#), [119](#).
- `Double subscript:` [1353](#).
- `Double superscript:` [1353](#).
- `double_hyphen_demerits:` [254](#), [1033](#).
- `\doublehyphendemerits` primitive: [256](#).
- `double_hyphen_demerits_code:` [254](#), [255](#), [256](#).
- `Doubly free location...:` [187](#).
- `down_ptr:` [632](#), [633](#), [634](#), [642](#).
- `downdate_width:` [1034](#).
- `down1:` [612](#), [613](#), [634](#), [636](#), [637](#), [640](#), [641](#), [643](#), [719](#), [726](#).
- `down2:` [612](#), [621](#), [637](#).
- `down3:` [612](#), [637](#).
- `down4:` [612](#), [637](#).
- `\dp` primitive: [442](#).
- `dry rot:` [95](#).
- `ds:` [712](#).
- `\dump...only by INITEX:` [1513](#).
- `\dump` primitive: [1228](#).
- `dump_four_ASCII:` [1485](#).
- `dump_hh:` [1481](#), [1494](#), [1500](#).
- `dump_int:` [1481](#), [1483](#), [1485](#), [1487](#), [1489](#), [1491](#), [1492](#), [1494](#), [1496](#), [1498](#), [1500](#), [1502](#), [1504](#), [1651](#).
- `dump_qqqq:` [1481](#), [1485](#), [1498](#).
- `dump_wd:` [1481](#), [1487](#), [1491](#), [1492](#), [1496](#).
- `dumpimagemeta:` [1502](#).

- dumputunicode*: [1502](#).
- Duplicate pattern**: [1138](#).
- dvi_buf*: [621](#), [622](#), [624](#), [625](#), [634](#), [640](#), [641](#).
- dvi_buf_size*: [11](#), [14](#), [621](#), [622](#), [623](#), [625](#), [626](#), [634](#), [640](#), [641](#), [670](#).
- dvi_f*: [643](#), [645](#), [648](#), [649](#).
- dvi_file*: [558](#), [619](#), [622](#), [624](#), [670](#).
- DVI files: [610](#).
- dvi_font_def*: [629](#), [649](#), [671](#).
- dvi_four*: [627](#), [629](#), [637](#), [645](#), [652](#), [661](#), [668](#), [670](#), [1612](#).
- dvi_gone*: [621](#), [622](#), [623](#), [625](#), [639](#).
- dvi_h*: [643](#), [645](#), [647](#), [648](#), [651](#), [652](#), [656](#), [657](#), [660](#), [665](#).
- dvi_index*: [621](#), [622](#), [624](#).
- dvi_limit*: [621](#), [622](#), [623](#), [625](#), [626](#).
- dvi_offset*: [621](#), [622](#), [623](#), [625](#), [628](#), [632](#), [634](#), [640](#), [641](#), [647](#), [657](#), [668](#), [670](#).
- dvi_out*: [625](#), [627](#), [628](#), [629](#), [630](#), [636](#), [637](#), [645](#), [647](#), [648](#), [649](#), [652](#), [657](#), [661](#), [668](#), [670](#), [1612](#).
- dvi_pop*: [628](#), [647](#), [657](#).
- dvi_ptr*: [621](#), [622](#), [623](#), [625](#), [626](#), [628](#), [634](#), [647](#), [657](#), [668](#), [670](#).
- dvi_ship_out*: [666](#), [791](#).
- dvi_swap*: [625](#).
- dvi_v*: [643](#), [645](#), [647](#), [651](#), [656](#), [657](#), [660](#), [665](#).
- dvi_x*: [691](#).
- dvi_y*: [691](#).
- dw*: [821](#).
- dyn_used*: [135](#), [138](#), [139](#), [140](#), [141](#), [182](#), [667](#), [1487](#), [1488](#).
- e*: [299](#), [301](#), [524](#), [544](#), [545](#), [556](#), [1374](#), [1387](#), [1412](#), [1658](#), [1659](#), [1741](#), [1779](#), [1836](#), [1837](#).
- easy_line*: [993](#), [1009](#), [1021](#), [1022](#), [1024](#).
- ec*: [566](#), [567](#), [569](#), [571](#), [586](#), [591](#), [592](#), [596](#), [603](#), [706](#).
- \edef** primitive: [1384](#).
- edge*: [647](#), [651](#), [654](#), [657](#), [663](#), [729](#), [733](#), [736](#), [738](#), [745](#), [1643](#), [1644](#).
- edge_dist*: [1716](#), [1717](#), [1719](#), [1726](#).
- edge_node*: [643](#), [1716](#), [1717](#), [1722](#), [1733](#).
- edge_node_size*: [1716](#).
- ef*: [821](#).
- \efcode** primitive: [1430](#).
- ef_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- eight_bits*: [25](#), [64](#), [130](#), [319](#), [575](#), [586](#), [597](#), [604](#), [608](#), [609](#), [622](#), [634](#), [673](#), [680](#), [686](#), [690](#), [696](#), [704](#), [705](#), [707](#), [712](#), [725](#), [821](#), [880](#), [883](#), [886](#), [1167](#), [1168](#), [1464](#).
- eject_penalty*: [175](#), [1003](#), [1005](#), [1025](#), [1033](#), [1047](#), [1145](#), [1147](#), [1149](#), [1180](#), [1185](#), [1186](#).
- el_gordo*: [111](#), [112](#), [114](#).
- \pdfelapsedtime** primitive: [442](#).
- elapsed_time_code*: [442](#), [443](#), [450](#).
- else**: [10](#).
- \else** primitive: [517](#).
- else_code*: [515](#), [517](#), [524](#), [1665](#).
- em**: [481](#).
- Emergency stop**: [93](#).
- emergency_stretch*: [265](#), [1002](#), [1037](#).
- \emergencystretch** primitive: [266](#).
- emergency_stretch_code*: [265](#), [266](#).
- empty*: [16](#), [447](#), [855](#), [859](#), [861](#), [866](#), [896](#), [897](#), [912](#), [923](#), [925](#), [926](#), [928](#), [929](#), [930](#), [1155](#), [1161](#), [1162](#), [1166](#), [1176](#), [1183](#), [1352](#), [1353](#), [1362](#).
- empty line at end of file: [512](#), [564](#).
- empty_field*: [858](#), [859](#), [860](#), [916](#), [1339](#), [1341](#), [1357](#).
- empty_flag*: [142](#), [144](#), [148](#), [168](#), [182](#), [1488](#).
- end**: [7](#), [8](#), [10](#).
- End of file on the terminal: [37](#), [71](#).
- (**\end** occurred...): [1513](#).
- \end** primitive: [1228](#).
- end_cs_name*: [226](#), [287](#), [288](#), [398](#), [1310](#), [1764](#).
- \endcsname** primitive: [287](#).
- end_diagnostic*: [263](#), [306](#), [321](#), [345](#), [426](#), [427](#), [528](#), [535](#), [608](#), [666](#), [669](#), [750](#), [837](#), [849](#), [1000](#), [1037](#), [1162](#), [1167](#), [1181](#), [1186](#), [1297](#), [1474](#), [1659](#), [1820](#).
- end_file_reading*: [351](#), [352](#), [382](#), [384](#), [509](#), [563](#), [1513](#).
- end_graf*: [1201](#), [1261](#), [1270](#), [1272](#), [1276](#), [1307](#), [1309](#), [1344](#).
- end_group*: [226](#), [287](#), [288](#), [1239](#).
- \endgroup** primitive: [287](#).
- \endinput** primitive: [402](#).
- end_L_code*: [165](#), [1698](#), [1699](#), [1702](#), [1731](#).
- end_line_char*: [87](#), [254](#), [258](#), [325](#), [340](#), [354](#), [382](#), [384](#), [509](#), [560](#), [564](#), [1515](#).
- \endlinechar** primitive: [256](#).
- end_line_char_code*: [254](#), [255](#), [256](#).
- end_line_char_inactive*: [382](#), [384](#), [509](#), [564](#), [1515](#).
- end_link*: [1632](#), [1642](#).
- end_LR*: [165](#), [210](#), [1705](#), [1708](#), [1714](#), [1725](#), [1734](#), [1736](#).
- end_LR_type*: [165](#), [1702](#), [1705](#), [1708](#), [1714](#), [1725](#), [1734](#), [1736](#).
- end_M*: [1256](#).
- end_M_code*: [165](#), [450](#), [1702](#), [1743](#).
- end_match*: [225](#), [311](#), [313](#), [316](#), [417](#), [418](#), [420](#).
- end_match_token*: [311](#), [415](#), [417](#), [418](#), [419](#), [420](#), [500](#), [502](#), [508](#).
- end_name*: [538](#), [543](#), [552](#), [557](#).
- end_of_TEX*: [6](#), [81](#), [1510](#).
- end_R_code*: [165](#), [1698](#), [1702](#).
- end_reflect*: [1697](#).
- end_span*: [180](#), [942](#), [953](#), [967](#), [971](#), [975](#), [977](#).

- end_template*: [228](#), [388](#), [401](#), [406](#), [954](#), [1471](#), [1769](#).
end_template_token: [954](#), [958](#), [964](#).
end_thread: [1634](#), [1636](#).
end_token_list: [346](#), [347](#), [379](#), [416](#), [1201](#), [1513](#), [1615](#).
end_write: [240](#), [1613](#), [1615](#).
\endwrite: [1613](#).
end_write_token: [1615](#), [1616](#).
endcases: [10](#).
\endL primitive: [1698](#).
\endR primitive: [1698](#).
endtemplate: [954](#).
endv: [225](#), [320](#), [401](#), [406](#), [942](#), [954](#), [956](#), [965](#), [1222](#), [1306](#), [1307](#).
ensure_dvi_open: [558](#), [645](#).
ensure_pdf_open: [683](#), [684](#).
ensure_vbox: [1168](#), [1184](#), [1193](#).
eof: [26](#), [31](#), [52](#), [590](#), [602](#), [772](#), [1505](#).
eof_seen: [350](#), [384](#), [1657](#).
coln: [31](#), [52](#).
eop: [610](#), [612](#), [613](#), [615](#), [668](#), [670](#).
epdf_orig_x: [498](#), [1634](#).
epdf_orig_y: [498](#), [1634](#).
epochseconds: [680](#), [1515](#), [1553](#), [1582](#), [1584](#).
eq_define: [299](#), [300](#), [301](#), [398](#), [956](#), [1246](#), [1390](#).
eq_destroy: [297](#), [299](#), [301](#), [305](#).
eq_level: [239](#), [240](#), [246](#), [250](#), [254](#), [271](#), [277](#), [286](#), [299](#), [301](#), [305](#), [954](#), [1152](#), [1491](#), [1613](#), [1817](#), [1818](#).
eq_level_field: [239](#).
eq_no: [226](#), [1316](#), [1317](#), [1319](#), [1320](#), [1676](#).
\eqno primitive: [1317](#).
eq_save: [298](#), [299](#), [300](#).
eq_type: [228](#), [239](#), [240](#), [241](#), [246](#), [250](#), [271](#), [277](#), [286](#), [287](#), [289](#), [299](#), [301](#), [373](#), [375](#), [376](#), [379](#), [380](#), [398](#), [415](#), [417](#), [954](#), [1328](#), [1491](#), [1613](#), [1764](#).
eq_type_field: [239](#), [297](#).
eq_word_define: [300](#), [301](#), [1246](#), [1315](#), [1321](#), [1390](#).
eqtb: [2](#), [133](#), [181](#), [238](#), [239](#), [240](#), [241](#), [242](#), [246](#), [248](#), [250](#), [254](#), [258](#), [260](#), [265](#), [268](#), [269](#), [270](#), [271](#), [273](#), [275](#), [284](#), [286](#), [287](#), [288](#), [289](#), [290](#), [292](#), [294](#), [296](#), [297](#), [298](#), [299](#), [300](#), [301](#), [303](#), [304](#), [305](#), [306](#), [307](#), [308](#), [311](#), [313](#), [319](#), [320](#), [327](#), [329](#), [354](#), [355](#), [376](#), [415](#), [439](#), [440](#), [499](#), [517](#), [574](#), [579](#), [706](#), [954](#), [988](#), [1364](#), [1384](#), [1398](#), [1413](#), [1429](#), [1433](#), [1491](#), [1492](#), [1493](#), [1517](#), [1523](#), [1646](#), [1820](#), [1832](#).
eqtb_size: [238](#), [265](#), [268](#), [270](#), [271](#), [272](#), [1483](#), [1484](#), [1492](#), [1493](#).
equiv: [239](#), [240](#), [241](#), [242](#), [246](#), [247](#), [248](#), [250](#), [251](#), [252](#), [253](#), [271](#), [273](#), [277](#), [286](#), [287](#), [289](#), [297](#), [299](#), [301](#), [373](#), [375](#), [376](#), [379](#), [380](#), [439](#), [440](#), [441](#), [534](#), [604](#), [706](#), [954](#), [1328](#), [1403](#), [1413](#), [1465](#), [1491](#), [1613](#), [1655](#), [1861](#), [1863](#).
equiv_field: [239](#), [297](#), [307](#), [1831](#).
err_help: [79](#), [248](#), [1459](#), [1460](#).
\errhelp primitive: [248](#).
err_help_loc: [248](#).
\errmessage primitive: [1453](#).
error: [72](#), [75](#), [76](#), [78](#), [79](#), [82](#), [88](#), [91](#), [93](#), [98](#), [121](#), [349](#), [360](#), [368](#), [396](#), [424](#), [434](#), [444](#), [454](#), [471](#), [480](#), [482](#), [485](#), [486](#), [497](#), [501](#), [502](#), [512](#), [526](#), [536](#), [549](#), [561](#), [587](#), [593](#), [606](#), [669](#), [897](#), [950](#), [958](#), [966](#), [1000](#), [1111](#), [1112](#), [1135](#), [1136](#), [1137](#), [1138](#), [1151](#), [1153](#), [1167](#), [1179](#), [1184](#), [1199](#), [1202](#), [1226](#), [1240](#), [1242](#), [1244](#), [1245](#), [1256](#), [1258](#), [1271](#), [1275](#), [1282](#), [1286](#), [1296](#), [1297](#), [1304](#), [1305](#), [1311](#), [1335](#), [1342](#), [1353](#), [1359](#), [1368](#), [1371](#), [1389](#), [1401](#), [1408](#), [1412](#), [1413](#), [1417](#), [1428](#), [1435](#), [1459](#), [1460](#), [1469](#), [1537](#), [1616](#), [1653](#), [1779](#).
error_context_lines: [254](#), [333](#).
\errorcontextlines primitive: [256](#).
error_context_lines_code: [254](#), [255](#), [256](#).
error_count: [76](#), [77](#), [82](#), [86](#), [1272](#), [1469](#).
error_line: [11](#), [14](#), [54](#), [58](#), [328](#), [333](#), [337](#), [338](#), [339](#).
error_message_issued: [76](#), [82](#), [95](#).
error_stop_mode: [72](#), [73](#), [74](#), [82](#), [83](#), [93](#), [98](#), [686](#), [1438](#), [1459](#), [1469](#), [1470](#), [1473](#), [1505](#), [1513](#), [1693](#).
\errorstopmode primitive: [1438](#).
erstat: [27](#).
escape: [225](#), [250](#), [366](#), [1515](#).
escape_char: [254](#), [258](#), [261](#).
\escapechar primitive: [256](#).
escape_char_code: [254](#), [255](#), [256](#).
escapehex: [497](#).
escapename: [497](#).
escapestring: [497](#).
etc: [200](#).
ETC: [314](#).
eTeX_aux: [230](#), [231](#), [233](#), [234](#).
eTeX_aux_field: [230](#), [231](#), [1676](#).
eTeX_banner: [2](#).
etex_convert_base: [494](#).
etex_convert_codes: [494](#).
eTeX_dim: [442](#), [450](#), [1666](#), [1669](#), [1798](#).
eTeX_enabled: [1653](#), [1700](#).
eTeX_ex: [202](#), [296](#), [299](#), [300](#), [304](#), [348](#), [562](#), [608](#), [653](#), [666](#), [735](#), [750](#), [1321](#), [1387](#), [1388](#), [1389](#), [1487](#), [1488](#), [1513](#), [1515](#), [1649](#), [1652](#), [1711](#), [1712](#), [1713](#), [1731](#).
eTeX_expr: [442](#), [1775](#), [1776](#), [1777](#).
eTeX_glue: [442](#), [450](#), [1802](#).
eTeX_int: [442](#), [1646](#), [1660](#), [1663](#), [1798](#).
etex_int_base: [254](#).
etex_int_pars: [254](#).
eTeX_mode: [1645](#), [1649](#), [1650](#), [1651](#), [1652](#).

- eTeX_mu*: [442](#), [1777](#), [1802](#).
- etex_pen_base*: [248](#), [250](#), [251](#).
- etex_pens*: [248](#), [250](#), [251](#).
- eTeX_revision*: [2](#), [498](#).
- `\eTeXrevision` primitive: [1646](#).
- eTeX_revision_code*: [494](#), [495](#), [497](#), [498](#), [1646](#).
- eTeX_state*: [1646](#), [1651](#), [1697](#).
- eTeX_state_base*: [1646](#), [1698](#).
- eTeX_state_code*: [254](#), [1646](#), [1697](#).
- eTeX_states*: [2](#), [254](#), [1651](#).
- eTeX_text_offset*: [329](#).
- etex_toks*: [248](#).
- etex_toks_base*: [248](#).
- eTeX_version*: [2](#), [1648](#).
- `\eTeXversion` primitive: [1646](#).
- eTeX_version_code*: [442](#), [1646](#), [1647](#), [1648](#).
- eTeX_version_string*: [2](#).
- every_cr*: [248](#), [948](#), [973](#).
- `\everycr` primitive: [248](#).
- every_cr_loc*: [248](#), [249](#).
- every_cr_text*: [329](#), [336](#), [948](#), [973](#).
- every_display*: [248](#), [1321](#).
- `\everydisplay` primitive: [248](#).
- every_display_loc*: [248](#), [249](#).
- every_display_text*: [329](#), [336](#), [1321](#).
- every_eof*: [384](#), [1655](#).
- `\everyeof` primitive: [1654](#).
- every_eof_loc*: [248](#), [329](#), [1654](#), [1655](#).
- every_eof_text*: [329](#), [336](#), [384](#).
- every_hbox*: [248](#), [1259](#).
- `\everyhbox` primitive: [248](#).
- every_hbox_loc*: [248](#), [249](#).
- every_hbox_text*: [329](#), [336](#), [1259](#).
- every_job*: [248](#), [1205](#).
- `\everyjob` primitive: [248](#).
- every_job_loc*: [248](#), [249](#).
- every_job_text*: [329](#), [336](#), [1205](#).
- every_math*: [248](#), [1315](#).
- `\everymath` primitive: [248](#).
- every_math_loc*: [248](#), [249](#).
- every_math_text*: [329](#), [336](#), [1315](#).
- every_par*: [248](#), [1267](#).
- `\everypar` primitive: [248](#).
- every_par_loc*: [248](#), [249](#), [329](#), [1402](#).
- every_par_text*: [329](#), [336](#), [1267](#).
- every_vbox*: [248](#), [1259](#), [1343](#).
- `\everyvbox` primitive: [248](#).
- every_vbox_loc*: [248](#), [249](#).
- every_vbox_text*: [329](#), [336](#), [1259](#), [1343](#).
- ex*: [481](#).
- ex_hyphen_penalty*: [163](#), [254](#), [1043](#).
- `\exhyphenpenalty` primitive: [256](#).
- ex_hyphen_penalty_code*: [254](#), [255](#), [256](#).
- ex_ratio*: [821](#).
- ex_space*: [226](#), [287](#), [288](#), [1205](#), [1266](#).
- exactly*: [814](#), [815](#), [889](#), [1064](#), [1152](#), [1192](#), [1238](#), [1377](#), [1677](#).
- exit*: [15](#), [16](#), [37](#), [47](#), [58](#), [59](#), [69](#), [82](#), [122](#), [143](#), [200](#), [299](#), [300](#), [314](#), [363](#), [415](#), [433](#), [439](#), [487](#), [491](#), [496](#), [523](#), [524](#), [550](#), [604](#), [609](#), [634](#), [642](#), [749](#), [793](#), [821](#), [842](#), [926](#), [965](#), [1003](#), [1070](#), [1109](#), [1119](#), [1123](#), [1152](#), [1169](#), [1187](#), [1205](#), [1230](#), [1255](#), [1281](#), [1286](#), [1289](#), [1295](#), [1327](#), [1335](#), [1350](#), [1387](#), [1412](#), [1446](#), [1479](#), [1513](#), [1516](#), [1658](#), [1769](#), [1816](#), [1818](#).
- expand*: [380](#), [388](#), [392](#), [394](#), [397](#), [406](#), [407](#), [465](#), [493](#), [504](#), [524](#), [536](#), [956](#), [1679](#), [1769](#).
- expand_after*: [228](#), [287](#), [288](#), [388](#), [391](#), [1759](#).
- `\expandafter` primitive: [287](#).
- expand_depth*: [1779](#).
- expand_depth_count*: [1779](#).
- expand_font*: [705](#), [821](#).
- expand_font_name*: [705](#).
- expand_ratio*: [705](#).
- `\expanded` primitive: [494](#).
- expanded_code*: [494](#), [495](#), [497](#).
- explicit*: [173](#), [674](#), [891](#), [1011](#), [1040](#), [1042](#), [1053](#), [1234](#), [1289](#), [1708](#).
- expr_a*: [1789](#), [1791](#).
- expr_add*: [1780](#), [1781](#).
- expr_add_sub*: [1789](#).
- expr_d*: [1793](#).
- expr_div*: [1780](#), [1781](#), [1792](#), [1793](#).
- expr_e_field*: [1785](#), [1786](#).
- expr_m*: [1792](#).
- expr_mult*: [1780](#), [1781](#), [1792](#).
- expr_n_field*: [1785](#), [1786](#).
- expr_node_size*: [1785](#), [1786](#).
- expr_none*: [1780](#), [1781](#), [1788](#), [1789](#).
- expr_s*: [1795](#).
- expr_scale*: [1780](#), [1792](#), [1795](#).
- expr_sub*: [1780](#), [1781](#), [1787](#), [1789](#).
- expr_t_field*: [1785](#), [1786](#).
- ext_bot*: [572](#), [887](#), [888](#).
- ext_delimiter*: [539](#), [541](#), [542](#), [543](#).
- ext_mid*: [572](#), [887](#), [888](#).
- ext_rep*: [572](#), [887](#), [888](#).
- ext_tag*: [570](#), [595](#), [604](#), [705](#), [882](#), [884](#).
- ext_top*: [572](#), [887](#), [888](#).
- ext_xn_over_d*: [821](#), [1550](#), [1634](#).
- exten*: [570](#).
- exten_base*: [576](#), [578](#), [592](#), [600](#), [601](#), [603](#), [705](#), [706](#), [887](#), [1498](#), [1499](#).
- extensible_recipe*: [567](#), [572](#).
- extension*: [226](#), [1522](#), [1524](#), [1525](#), [1620](#).

extensions to TeX: [2](#), [164](#), [1518](#).

Extra `\else`: [536](#).

Extra `\endcsname`: [1311](#).

Extra `\fi`: [536](#).

Extra `\middle.`: [1368](#).

Extra `\or`: [526](#), [536](#).

Extra `\right.`: [1368](#).

Extra `}`, or forgotten `x`: [1245](#).

Extra alignment tab...: [966](#).

Extra `x`: [1242](#).

`extra_info`: [943](#), [962](#), [963](#), [965](#), [966](#).

`extra_right_brace`: [1244](#), [1245](#).

`extra_space`: [573](#), [584](#), [1220](#).

`extra_space_code`: [573](#), [584](#).

eyes and mouth: [354](#).

`e1`: [793](#).

`e2`: [793](#).

`f`: [27](#), [28](#), [31](#), [112](#), [114](#), [162](#), [474](#), [551](#), [586](#), [604](#),
[605](#), [608](#), [609](#), [619](#), [629](#), [706](#), [720](#), [725](#), [821](#), [880](#),
[883](#), [885](#), [886](#), [889](#), [890](#), [891](#), [912](#), [1004](#), [1036](#),
[1244](#), [1289](#), [1299](#), [1314](#), [1387](#), [1433](#), [1779](#), [1796](#).

`false`: [27](#), [31](#), [37](#), [45](#), [46](#), [47](#), [51](#), [76](#), [80](#), [88](#), [89](#),
[98](#), [106](#), [107](#), [112](#), [115](#), [184](#), [185](#), [186](#), [187](#), [286](#),
[296](#), [303](#), [306](#), [321](#), [333](#), [345](#), [349](#), [350](#), [353](#), [358](#),
[368](#), [383](#), [384](#), [387](#), [390](#), [400](#), [426](#), [427](#), [433](#), [441](#),
[451](#), [453](#), [466](#), [467](#), [471](#), [473](#), [474](#), [475](#), [481](#), [486](#),
[487](#), [488](#), [491](#), [498](#), [511](#), [527](#), [528](#), [531](#), [533](#), [535](#),
[538](#), [542](#), [550](#), [552](#), [554](#), [564](#), [577](#), [589](#), [608](#), [620](#),
[681](#), [683](#), [685](#), [686](#), [688](#), [689](#), [692](#), [693](#), [698](#), [702](#),
[705](#), [706](#), [720](#), [726](#), [727](#), [749](#), [753](#), [769](#), [775](#), [793](#),
[794](#), [795](#), [797](#), [799](#), [800](#), [802](#), [803](#), [805](#), [821](#), [880](#),
[894](#), [896](#), [928](#), [948](#), [965](#), [1000](#), [1002](#), [1003](#), [1011](#),
[1025](#), [1028](#), [1037](#), [1055](#), [1061](#), [1078](#), [1081](#), [1085](#),
[1086](#), [1126](#), [1129](#), [1135](#), [1136](#), [1137](#), [1138](#), [1141](#),
[1143](#), [1162](#), [1165](#), [1181](#), [1186](#), [1195](#), [1196](#), [1201](#),
[1206](#), [1208](#), [1209](#), [1210](#), [1216](#), [1227](#), [1230](#), [1237](#),
[1256](#), [1272](#), [1277](#), [1343](#), [1358](#), [1359](#), [1367](#), [1368](#),
[1370](#), [1375](#), [1402](#), [1403](#), [1412](#), [1434](#), [1446](#), [1455](#),
[1458](#), [1459](#), [1464](#), [1479](#), [1501](#), [1514](#), [1520](#), [1521](#),
[1530](#), [1532](#), [1535](#), [1550](#), [1553](#), [1562](#), [1563](#), [1576](#),
[1577](#), [1579](#), [1580](#), [1597](#), [1615](#), [1619](#), [1620](#), [1626](#),
[1627](#), [1636](#), [1642](#), [1645](#), [1653](#), [1659](#), [1679](#), [1753](#),
[1766](#), [1771](#), [1773](#), [1779](#), [1790](#), [1794](#), [1796](#), [1817](#),
[1818](#), [1820](#), [1821](#), [1840](#), [1843](#), [1850](#), [1852](#), [1853](#).

`false_bchar`: [1207](#), [1209](#), [1213](#).

`fam`: [855](#), [856](#), [857](#), [861](#), [865](#), [896](#), [897](#), [926](#), [927](#),
[1327](#), [1331](#), [1341](#).

`\fam` primitive: [256](#).

`fam_fnt`: [248](#), [874](#), [875](#), [881](#), [896](#), [1371](#).

`fam_in_range`: [1327](#), [1331](#), [1341](#).

`fast_delete_glue_ref`: [219](#), [220](#), [1696](#).

`fast_get_avail`: [140](#), [224](#), [397](#), [700](#), [820](#), [821](#),

[1209](#), [1213](#).

`fast_store_new_token`: [397](#), [425](#), [490](#), [492](#).

Fatal format file error: [1479](#).

`fatal_error`: [71](#), [93](#), [346](#), [382](#), [510](#), [556](#), [561](#), [956](#),
[963](#), [965](#), [1307](#).

`fatal_error_stop`: [76](#), [77](#), [82](#), [93](#), [1510](#), [1511](#).

`fbyte`: [590](#), [594](#), [597](#), [602](#).

Ferguson, Michael John: [2](#).

`fetch`: [896](#), [898](#), [912](#), [915](#), [923](#), [926](#), [929](#).

`fetch_box`: [446](#), [497](#), [531](#), [1152](#), [1255](#), [1286](#), [1423](#),
[1472](#), [1546](#), [1817](#).

`fetch_effective_tail`: [1256](#), [1257](#), [1281](#).

`fetch_effective_tail_eTeX`: [1256](#).

`fewest_demerits`: [1046](#), [1048](#), [1049](#).

`ff`: [498](#), [693](#), [696](#), [698](#), [766](#).

`fget`: [590](#), [591](#), [594](#), [597](#), [602](#).

`\fi` primitive: [517](#).

`fi_code`: [515](#), [517](#), [518](#), [520](#), [524](#), [526](#), [535](#), [536](#),
[1665](#), [1688](#), [1774](#).

`fi_or_else`: [228](#), [321](#), [388](#), [391](#), [515](#), [517](#), [518](#),
[520](#), [536](#), [1469](#).

`fil`: [480](#).

`fil`: [153](#), [168](#), [182](#), [195](#), [480](#), [822](#), [833](#), [839](#), [1377](#).

`fil_code`: [1234](#), [1235](#), [1236](#).

`fil_glue`: [180](#), [182](#), [1236](#).

`fil_neg_code`: [1234](#), [1236](#).

`fil_neg_glue`: [180](#), [182](#), [1236](#).

File ended while scanning...: [360](#).

File ended within `\read`: [512](#).

`file_name_size`: [11](#), [26](#), [545](#), [548](#), [549](#), [551](#).

`file_offset`: [54](#), [55](#), [57](#), [58](#), [62](#), [563](#), [666](#), [750](#),
[1456](#), [1752](#).

`file_opened`: [586](#), [587](#), [589](#).

`file_warning`: [384](#), [1774](#).

`filename`: [712](#).

`fill`: [153](#), [168](#), [182](#), [822](#), [833](#), [839](#), [1377](#).

`fill_code`: [1234](#), [1235](#), [1236](#).

`fill_glue`: [180](#), [182](#), [1230](#), [1236](#).

`fill_width`: [1839](#), [1840](#), [1843](#).

`filll`: [153](#), [168](#), [195](#), [480](#), [822](#), [833](#), [839](#), [1377](#), [1696](#).

`fin_align`: [947](#), [959](#), [974](#), [1307](#).

`fin_col`: [947](#), [965](#), [1307](#).

`fin_mlist`: [1350](#), [1360](#), [1362](#), [1367](#), [1370](#).

`fin_row`: [947](#), [973](#), [1307](#).

`fin_rule`: [647](#), [650](#), [654](#), [657](#), [659](#), [663](#), [729](#), [732](#),
[736](#), [738](#), [741](#), [745](#).

`final_cleanup`: [1510](#), [1511](#), [1513](#), [1822](#).

`final_end`: [6](#), [35](#), [353](#), [1510](#), [1515](#).

`final_hyphen_demerits`: [254](#), [1033](#).

`\finalhyphendemerits` primitive: [256](#).

`final_hyphen_demerits_code`: [254](#), [255](#), [256](#).

`final_pass`: [1002](#), [1028](#), [1037](#), [1047](#).

- final_skip*: [695](#), [1571](#), [1600](#), [1634](#).
find_effective_tail: [450](#).
find_effective_tail_eTeX: [450](#), [1256](#).
find_font_dimen: [451](#), [605](#), [1218](#), [1429](#).
find_obj: [1553](#), [1563](#).
find_protchar_left: [819](#), [1003](#), [1061](#).
find_protchar_right: [819](#), [1003](#), [1055](#).
find_sa_element: [441](#), [453](#), [1400](#), [1402](#), [1403](#), [1413](#),
[1813](#), [1816](#), [1817](#), [1818](#), [1821](#), [1824](#), [1827](#), [1836](#).
fingers: [537](#).
finite_shrink: [999](#), [1000](#).
fire_up: [1180](#), [1187](#), [1806](#), [1822](#), [1825](#).
fire_up_done: [1187](#), [1822](#), [1826](#).
fire_up_init: [1187](#), [1822](#), [1825](#).
firm_up_the_line: [362](#), [384](#), [385](#), [564](#).
first: [30](#), [31](#), [35](#), [36](#), [37](#), [71](#), [83](#), [87](#), [88](#), [286](#), [350](#),
[351](#), [353](#), [377](#), [382](#), [384](#), [385](#), [400](#), [509](#), [557](#),
[564](#), [1514](#), [1753](#), [1765](#).
first_child: [1135](#), [1138](#), [1139](#), [1852](#), [1853](#).
first_count: [54](#), [337](#), [338](#), [339](#).
first_fit: [1128](#), [1132](#), [1141](#), [1854](#).
first_indent: [1021](#), [1023](#), [1064](#).
first_mark: [408](#), [409](#), [1187](#), [1191](#), [1806](#), [1825](#).
\firstmark primitive: [410](#).
first_mark_code: [408](#), [410](#), [411](#), [1806](#).
\firstmarks primitive: [1806](#).
first_p: [997](#), [1003](#), [1037](#).
first_text_char: [19](#), [24](#).
first_width: [1021](#), [1023](#), [1024](#), [1064](#).
fit_class: [1004](#), [1010](#), [1019](#), [1020](#), [1026](#), [1027](#), [1029](#),
[1033](#), [1844](#), [1845](#), [1847](#), [1848](#).
fitness: [993](#), [1019](#), [1033](#), [1038](#).
fix_date_and_time: [259](#), [1510](#), [1515](#).
fix_expand_value: [705](#).
fix_int: [682](#), [683](#), [705](#), [706](#), [792](#), [821](#), [1550](#), [1573](#).
fix_language: [1209](#), [1621](#).
fix_pdf_draftmode: [747](#), [748](#).
fix_pdfoutput: [683](#), [747](#), [752](#), [791](#), [1511](#).
fix_word: [567](#), [568](#), [573](#), [574](#), [597](#).
fixed_decimal_digits: [690](#), [691](#), [692](#), [693](#), [792](#).
fixed_gamma: [680](#), [683](#).
fixed_gen_tounicode: [691](#), [799](#).
fixed_image_apply_gamma: [680](#), [683](#).
fixed_image_gamma: [680](#), [683](#).
fixed_image_hicolor: [680](#), [683](#).
fixed_inclusion_copy_font: [683](#), [691](#).
fixed_pdf_draftmode: [680](#), [683](#), [684](#), [685](#), [748](#),
[778](#), [794](#).
fixed_pdf_draftmode_set: [680](#), [681](#), [748](#).
fixed_pdf_major_version: [680](#), [683](#).
fixed_pdf_minor_version: [680](#), [683](#).
fixed_pdf_objcompresslevel: [680](#), [683](#), [698](#), [748](#).
fixed_pdfoutput: [680](#), [747](#), [1511](#).
fixed_pdfoutput_set: [680](#), [681](#), [747](#), [1511](#).
fixed_pk_resolution: [691](#), [792](#).
fixedi: [705](#).
float: [109](#), [132](#), [204](#), [653](#), [662](#), [735](#), [744](#), [983](#), [1635](#).
float_constant: [109](#), [204](#), [647](#), [653](#), [657](#), [729](#), [738](#),
[1299](#), [1301](#), [1634](#).
float_cost: [158](#), [206](#), [1183](#), [1276](#).
floating_penalty: [158](#), [254](#), [1244](#), [1276](#).
\floatingpenalty primitive: [256](#).
floating_penalty_code: [254](#), [255](#), [256](#).
flush_char: [42](#), [198](#), [213](#), [866](#), [869](#).
flush_jbig2_page0_objects: [794](#).
flush_list: [141](#), [218](#), [346](#), [398](#), [422](#), [433](#), [764](#),
[765](#), [975](#), [1078](#), [1135](#), [1272](#), [1455](#), [1473](#), [1614](#),
[1685](#), [1750](#), [1764](#).
flush_math: [892](#), [950](#), [1371](#).
flush_node_list: [217](#), [220](#), [297](#), [667](#), [772](#), [872](#), [892](#),
[905](#), [906](#), [916](#), [974](#), [990](#), [1053](#), [1057](#), [1078](#), [1093](#),
[1143](#), [1152](#), [1167](#), [1174](#), [1198](#), [1201](#), [1254](#), [1256](#),
[1281](#), [1296](#), [1297](#), [1382](#), [1513](#), [1563](#), [1620](#), [1632](#),
[1633](#), [1724](#), [1732](#), [1735](#), [1740](#), [1835](#).
flush_str: [497](#), [705](#), [706](#), [718](#), [726](#), [727](#), [769](#), [772](#),
[805](#), [1535](#), [1550](#), [1553](#), [1561](#), [1563](#), [1585](#), [1627](#).
flush_string: [44](#), [286](#), [563](#), [792](#), [1436](#), [1455](#), [1506](#),
[1553](#), [1750](#).
flush_whatsit_node: [772](#), [783](#), [786](#).
flushable: [673](#), [1553](#).
flushable_string: [1433](#), [1436](#).
fm: [1255](#), [1256](#), [1281](#).
fm_entry_ptr: [707](#), [708](#).
fmem_ptr: [451](#), [575](#), [578](#), [592](#), [595](#), [596](#), [603](#), [605](#),
[606](#), [607](#), [705](#), [706](#), [1496](#), [1497](#), [1499](#), [1512](#).
fnt_file: [550](#), [1481](#), [1482](#), [1484](#), [1505](#), [1506](#),
[1507](#), [1515](#).
fnt_def1: [612](#), [613](#), [629](#), [715](#).
fnt_def2: [612](#).
fnt_def3: [612](#).
fnt_def4: [612](#).
fnt_num_0: [612](#), [613](#), [649](#), [719](#), [726](#).
fnt1: [612](#), [613](#), [649](#), [719](#), [726](#).
fnt2: [612](#).
fnt3: [612](#).
fnt4: [612](#).
font: [152](#), [161](#), [162](#), [192](#), [194](#), [211](#), [224](#), [574](#), [609](#),
[648](#), [674](#), [705](#), [731](#), [820](#), [821](#), [823](#), [826](#), [855](#),
[883](#), [889](#), [898](#), [1015](#), [1016](#), [1040](#), [1041](#), [1044](#),
[1045](#), [1071](#), [1072](#), [1073](#), [1078](#), [1083](#), [1086](#), [1209](#),
[1213](#), [1289](#), [1323](#), [1721](#), [1730](#).
font metric files: [565](#).
font parameters: [874](#), [875](#).
Font x has only...: [606](#).

- Font x=xx not loadable...: 587.
 Font x=xx not loaded...: 593.
 \font primitive: 287.
 font_area: 575, 578, 603, 629, 630, 705, 706, 1436, 1498, 1499.
 font_base: 11, 12, 129, 152, 192, 194, 240, 250, 574, 577, 629, 649, 671, 673, 674, 705, 799, 1436, 1496, 1497, 1512.
 font_bc: 575, 578, 603, 604, 609, 673, 705, 706, 882, 896, 1211, 1498, 1499, 1668, 1766.
 font_bchar: 575, 578, 603, 705, 706, 1072, 1073, 1090, 1207, 1209, 1498, 1499.
 \fontchar_{dp} primitive: 1666.
 font_char_dp_code: 1666, 1667, 1668.
 \fontcharht primitive: 1666.
 font_char_ht_code: 1666, 1667, 1668.
 \fontcharic primitive: 1666.
 font_char_ic_code: 1666, 1667, 1668.
 \fontcharwd primitive: 1666.
 font_char_wd_code: 1666, 1667, 1668.
 font_check: 575, 594, 629, 712, 714, 1498, 1499.
 \fontdimen primitive: 287.
 font_dsize: 192, 498, 575, 578, 594, 629, 705, 706, 712, 714, 1436, 1437, 1498, 1499.
 font_ec: 575, 578, 603, 604, 609, 673, 705, 706, 882, 896, 1211, 1498, 1499, 1668, 1766.
 font_expand_ratio: 819, 821, 823, 826, 832, 838.
 font_false_bchar: 575, 578, 603, 705, 706, 1207, 1209, 1498, 1499.
 font_glue: 575, 578, 603, 605, 705, 706, 1218, 1498, 1499.
 font_id_base: 240, 252, 274, 441, 574, 706, 1433.
 font_id_text: 192, 252, 274, 606, 705, 706, 1433, 1498.
 font_in_short_display: 191, 192, 211, 674, 837, 1038, 1517.
 font_index: 574, 575, 586, 821, 1081, 1207, 1387.
 font_info: 11, 451, 574, 575, 576, 578, 580, 583, 584, 586, 592, 595, 598, 600, 601, 602, 605, 607, 705, 706, 821, 874, 875, 887, 915, 926, 1084, 1207, 1214, 1218, 1387, 1429, 1496, 1497, 1517.
 font_max: 11, 129, 192, 194, 574, 577, 592, 674, 705, 706, 1497, 1512.
 font_mem_size: 11, 574, 592, 607, 705, 706, 1497, 1512.
 font_name: 192, 498, 575, 578, 603, 608, 629, 630, 693, 705, 706, 710, 712, 713, 714, 717, 1436, 1437, 1498, 1499.
 \fontname primitive: 494.
 font_name_code: 494, 495, 497, 498.
 font_params: 575, 578, 603, 605, 606, 607, 705, 706, 1371, 1498, 1499.
 font_ptr: 575, 578, 592, 603, 605, 671, 705, 706, 799, 1436, 1496, 1497, 1512.
 font_shrink: 821, 823, 826, 838.
 font_size: 192, 498, 575, 578, 594, 629, 692, 693, 705, 706, 712, 717, 726, 1436, 1437, 1498, 1499.
 font_step: 705.
 font_stretch: 821, 823, 826, 832.
 font_used: 497, 575, 577, 649, 671, 692, 693, 799, 1585.
 fontnum: 692.
 FONTx: 706, 1433.
 for accent: 209.
 Forbidden control sequence...: 360.
 force_eof: 353, 383, 384, 404.
 format_area_length: 546, 550.
 format_default_length: 546, 548, 549, 550.
 format_ext_length: 546, 549, 550.
 format_extension: 546, 555, 1506.
 format_ident: 35, 61, 562, 1475, 1476, 1477, 1504, 1505, 1506, 1515, 1645.
 forward: 78, 236, 303, 362, 388, 435, 646, 703, 728, 866, 867, 894, 948, 974, 1679, 1692, 1749, 1778, 1783, 1807.
 found: 15, 143, 146, 147, 278, 281, 363, 376, 378, 415, 418, 420, 474, 481, 499, 501, 503, 550, 634, 636, 639, 640, 641, 693, 705, 815, 880, 882, 894, 1003, 1025, 1070, 1098, 1106, 1109, 1116, 1128, 1130, 1314, 1322, 1323, 1324, 1412, 1413, 1676, 1680, 1730, 1735, 1736, 1779, 1780, 1786, 1796, 1844, 1845.
 found1: 15, 693, 1070, 1077, 1478, 1491, 1676, 1796, 1797.
 found2: 15, 1070, 1078, 1478, 1492, 1676.
 four_cases: 710, 719, 726.
 four_choices: 131.
 four_quarters: 131, 439, 574, 575, 580, 581, 586, 712, 821, 857, 858, 880, 883, 886, 898, 912, 923, 1081, 1207, 1299, 1478, 1479, 1750, 1753.
 fract: 1795, 1796, 1843.
 fraction: 110, 112.
 fraction_four: 110, 111, 116, 119, 120.
 fraction_half: 111, 116, 127.
 fraction_noad: 110, 857, 861, 864, 872, 907, 935, 1354, 1357.
 fraction_noad_size: 857, 872, 935, 1357.
 fraction_one: 110, 111, 112, 113, 114, 124, 125.
 fraction_rule: 878, 879, 909, 921.
 free: 183, 185, 186, 187, 188, 189.
 free_avail: 139, 220, 222, 235, 426, 478, 497, 820, 946, 1090, 1211, 1286, 1402, 1464, 1575, 1680, 1702, 1754.
 free_node: 148, 219, 220, 297, 522, 642, 821, 829,

- 872, 889, 895, 901, 925, 927, 930, 934, 946, 977, 1034, 1035, 1039, 1078, 1085, 1152, 1194, 1196, 1197, 1212, 1276, 1286, 1362, 1363, 1377, 1513, 1534, 1602, 1719, 1722, 1724, 1726, 1735, 1742, 1753, 1754, 1786, 1818, 1822, 1838.
- freeze_page_specs*: [1162](#), [1176](#), [1183](#).
- frozen_control_sequence*: [240](#), [277](#), [1391](#), [1490](#), [1494](#), [1495](#).
- frozen_cr*: [240](#), [361](#), [954](#), [1308](#).
- frozen_dont_expand*: [240](#), [277](#), [393](#).
- frozen_end_group*: [240](#), [287](#), [1241](#).
- frozen_end_template*: [240](#), [401](#), [954](#).
- frozen_endv*: [240](#), [401](#), [406](#), [954](#).
- frozen_fi*: [240](#), [358](#), [517](#).
- frozen_null_font*: [240](#), [284](#), [285](#), [579](#).
- frozen_primitive*: [240](#), [277](#), [394](#), [466](#).
- frozen_protection*: [240](#), [1391](#), [1392](#).
- frozen_relax*: [240](#), [287](#), [395](#), [405](#).
- frozen_right*: [240](#), [1241](#), [1364](#).
- fs*: [705](#), [712](#), [725](#).
- Fuchs, David Raymond: [2](#), [610](#), [618](#).
- `\futurelet` primitive: [1395](#).
- g*: [47](#), [200](#), [586](#), [619](#), [821](#), [842](#), [880](#), [890](#), [1841](#).
- g_order*: [647](#), [653](#), [657](#), [662](#), [729](#), [735](#), [738](#), [744](#), [1634](#), [1635](#), [1696](#), [1720](#).
- g_sign*: [647](#), [653](#), [657](#), [662](#), [729](#), [735](#), [738](#), [744](#), [1634](#), [1635](#), [1696](#), [1720](#).
- gap_amount*: [1634](#).
- garbage*: [180](#), [493](#), [496](#), [497](#), [1135](#), [1359](#), [1368](#), [1455](#).
- garbage_warning*: [794](#).
- `\gdef` primitive: [1384](#).
- gen_faked_interword_space*: [693](#), [1625](#), [1626](#), [1636](#), [1642](#).
- gen_running_link*: [730](#), [1625](#), [1626](#), [1636](#), [1642](#).
- geq_define*: [301](#), [956](#), [1390](#).
- geq_word_define*: [301](#), [310](#), [1188](#), [1390](#).
- get*: [26](#), [29](#), [31](#), [33](#), [511](#), [564](#), [590](#), [1482](#).
- get_auto_kern*: [173](#), [705](#), [1209](#), [1210](#), [1214](#).
- get_avail*: [138](#), [140](#), [222](#), [223](#), [234](#), [347](#), [348](#), [359](#), [361](#), [393](#), [394](#), [397](#), [398](#), [478](#), [499](#), [508](#), [609](#), [883](#), [946](#), [957](#), [958](#), [968](#), [1083](#), [1086](#), [1113](#), [1240](#), [1241](#), [1394](#), [1402](#), [1615](#), [1680](#), [1685](#), [1702](#), [1724](#), [1730](#), [1751](#), [1764](#).
- get_chardepth*: [673](#).
- get_charheight*: [673](#).
- get_charwidth*: [673](#).
- get_ef_code*: [452](#), [821](#).
- get_expand_font*: [705](#).
- get_fontbase*: [673](#).
- get_image_group_ref*: [1634](#).
- get_kern*: [821](#), [823](#).
- get_kn_ac_code*: [452](#), [705](#).
- get_kn_bc_code*: [452](#), [705](#).
- get_kn_bs_code*: [452](#), [705](#).
- get_lp_code*: [452](#), [821](#).
- get_microinterval*: [450](#), [1553](#).
- get_next*: [76](#), [319](#), [354](#), [358](#), [362](#), [363](#), [379](#), [382](#), [386](#), [387](#), [388](#), [393](#), [406](#), [407](#), [413](#), [415](#), [504](#), [520](#), [527](#), [533](#), [814](#), [1213](#), [1221](#), [1302](#), [1763](#).
- get_next_char*: [793](#).
- get_node*: [143](#), [149](#), [154](#), [157](#), [162](#), [163](#), [165](#), [169](#), [170](#), [171](#), [174](#), [176](#), [224](#), [521](#), [634](#), [821](#), [842](#), [860](#), [862](#), [863](#), [890](#), [946](#), [972](#), [1017](#), [1018](#), [1019](#), [1038](#), [1089](#), [1184](#), [1276](#), [1277](#), [1339](#), [1341](#), [1357](#), [1424](#), [1425](#), [1527](#), [1554](#), [1571](#), [1601](#), [1634](#), [1696](#), [1716](#), [1730](#), [1751](#), [1785](#), [1812](#), [1817](#), [1834](#).
- get_nullcs*: [673](#).
- get_nullfont*: [673](#).
- get_nullptr*: [673](#).
- get_obj*: [498](#), [752](#), [1553](#), [1627](#), [1634](#).
- get_pdf_compress_level*: [673](#).
- get_pdf_omit_charset*: [673](#).
- get_pdf_suppress_ptex_info*: [673](#).
- get_pdf_suppress_warning_dup_map*: [673](#).
- get_pdf_suppress_warning_page_group*: [673](#).
- get_pk_char_width*: [690](#).
- get_preamble_token*: [956](#), [957](#), [958](#).
- get_quad*: [673](#).
- get_r_token*: [706](#), [1391](#), [1394](#), [1397](#), [1400](#), [1401](#), [1433](#).
- get_resname_prefix*: [792](#).
- get_rp_code*: [452](#), [821](#).
- get_sa_ptr*: [1816](#), [1822](#), [1828](#).
- get_sh_bs_code*: [452](#), [705](#).
- get_slant*: [673](#).
- get_st_bs_code*: [452](#), [705](#).
- get_strings_started*: [47](#), [51](#), [1510](#).
- get_tag_code*: [452](#), [604](#).
- get_tex_dimen*: [673](#).
- get_tex_int*: [673](#).
- get_token*: [76](#), [78](#), [88](#), [386](#), [387](#), [392](#), [393](#), [394](#), [395](#), [418](#), [425](#), [468](#), [478](#), [497](#), [499](#), [500](#), [502](#), [503](#), [505](#), [509](#), [956](#), [1202](#), [1314](#), [1391](#), [1397](#), [1428](#), [1444](#), [1447](#), [1470](#), [1615](#), [1616](#), [1680](#), [1762](#), [1769](#).
- get_vpos*: [1634](#).
- get_x_height*: [673](#).
- get_x_or_protected*: [959](#), [965](#), [1769](#).
- get_x_token*: [386](#), [388](#), [398](#), [406](#), [407](#), [428](#), [430](#), [432](#), [433](#), [469](#), [470](#), [471](#), [478](#), [491](#), [505](#), [532](#), [552](#), [954](#), [1110](#), [1136](#), [1204](#), [1205](#), [1314](#), [1373](#), [1413](#), [1620](#), [1764](#), [1769](#).
- get_x_token_or_active_char*: [532](#).
- getc*: [712](#), [772](#).

- getcreationdate*: [497](#).
- getfiledump*: [497](#).
- getfilemoddate*: [497](#).
- getfilesize*: [497](#).
- getllx*: [1627](#), [1632](#).
- getlly*: [1627](#), [1632](#).
- getmatch*: [497](#).
- getmd5sum*: [497](#).
- geturx*: [1627](#), [1632](#).
- getury*: [1627](#), [1632](#).
- give_err_help*: [78](#), [89](#), [90](#), [1460](#).
- global*: [1390](#), [1394](#), [1417](#), [1836](#).
- global definitions: [239](#), [301](#), [305](#), [1837](#).
- `\global` primitive: [1384](#).
- global_box_flag*: [1247](#), [1253](#), [1417](#), [1678](#).
- global_defs*: [254](#), [956](#), [1390](#), [1394](#).
- `\globaldefs` primitive: [256](#).
- global_defs_code*: [254](#), [255](#), [256](#).
- glue_base*: [238](#), [240](#), [242](#), [244](#), [245](#), [246](#), [247](#), [270](#), [956](#).
- glue_break*: [1051](#), [1055](#).
- glue_error*: [1787](#).
- `\glueexpr` primitive: [1775](#).
- glue_node*: [167](#), [170](#), [171](#), [193](#), [201](#), [220](#), [224](#), [450](#), [498](#), [650](#), [659](#), [674](#), [705](#), [732](#), [741](#), [823](#), [843](#), [904](#), [906](#), [935](#), [990](#), [991](#), [1003](#), [1011](#), [1030](#), [1036](#), [1040](#), [1053](#), [1055](#), [1074](#), [1078](#), [1143](#), [1147](#), [1148](#), [1163](#), [1171](#), [1172](#), [1175](#), [1282](#), [1283](#), [1284](#), [1323](#), [1378](#), [1634](#), [1723](#), [1730](#), [1743](#).
- glue_offset*: [153](#), [177](#), [204](#).
- glue_ord*: [168](#), [473](#), [647](#), [657](#), [729](#), [738](#), [816](#), [821](#), [842](#), [965](#), [1634](#), [1720](#).
- glue_order*: [153](#), [154](#), [177](#), [203](#), [204](#), [647](#), [657](#), [729](#), [738](#), [831](#), [832](#), [838](#), [846](#), [847](#), [850](#), [943](#), [970](#), [975](#), [981](#), [983](#), [984](#), [985](#), [1324](#), [1634](#), [1720](#), [1737](#).
- glue_par*: [242](#), [940](#).
- glue_pars*: [242](#).
- glue_ptr*: [167](#), [170](#), [171](#), [193](#), [207](#), [208](#), [220](#), [224](#), [450](#), [653](#), [662](#), [705](#), [735](#), [744](#), [830](#), [845](#), [853](#), [906](#), [960](#), [967](#), [969](#), [976](#), [977](#), [983](#), [990](#), [1003](#), [1012](#), [1042](#), [1055](#), [1144](#), [1151](#), [1171](#), [1176](#), [1179](#), [1324](#), [1635](#), [1696](#), [1730](#), [1743](#), [1840](#), [1850](#).
- glue_ratio*: [109](#), [128](#), [131](#), [153](#), [204](#).
- glue_ref*: [228](#), [246](#), [297](#), [956](#), [1404](#), [1412](#).
- glue_ref_count*: [168](#), [169](#), [170](#), [171](#), [172](#), [182](#), [219](#), [221](#), [246](#), [940](#), [1219](#), [1236](#).
- glue_set*: [153](#), [154](#), [177](#), [204](#), [653](#), [662](#), [735](#), [744](#), [831](#), [832](#), [838](#), [846](#), [847](#), [850](#), [981](#), [983](#), [984](#), [985](#), [1324](#), [1635](#), [1696](#), [1737](#).
- glue_shrink*: [177](#), [203](#), [970](#), [973](#), [975](#), [984](#), [985](#).
- `\glueshrink` primitive: [1798](#).
- glue_shrink_code*: [1798](#), [1799](#), [1801](#).
- `\glueshrinkorder` primitive: [1798](#).
- glue_shrink_order_code*: [1798](#), [1799](#), [1800](#).
- glue_sign*: [153](#), [154](#), [177](#), [203](#), [204](#), [647](#), [657](#), [729](#), [738](#), [831](#), [832](#), [838](#), [846](#), [847](#), [850](#), [943](#), [970](#), [975](#), [981](#), [983](#), [984](#), [985](#), [1324](#), [1634](#), [1720](#), [1737](#).
- glue_spec_size*: [168](#), [169](#), [180](#), [182](#), [219](#), [890](#), [1696](#).
- glue_stretch*: [177](#), [203](#), [970](#), [973](#), [975](#), [984](#), [985](#).
- `\gluestretch` primitive: [1798](#).
- glue_stretch_code*: [1798](#), [1799](#), [1801](#).
- `\gluestretchorder` primitive: [1798](#).
- glue_stretch_order_code*: [1798](#), [1799](#), [1800](#).
- glue_temp*: [647](#), [653](#), [657](#), [662](#), [729](#), [735](#), [738](#), [744](#), [1634](#), [1635](#), [1720](#).
- `\gluetomu` primitive: [1802](#).
- glue_to_mu_code*: [1802](#), [1803](#), [1805](#).
- glue_val*: [436](#), [437](#), [439](#), [442](#), [443](#), [450](#), [453](#), [455](#), [456](#), [477](#), [487](#), [491](#), [956](#), [1236](#), [1404](#), [1412](#), [1413](#), [1414](#), [1416](#), [1571](#), [1775](#), [1776](#), [1777](#), [1779](#), [1782](#), [1784](#), [1788](#), [1793](#), [1812](#), [1820](#), [1829](#).
- glyph_to_unicode*: [1585](#), [1590](#).
- goal height: [1161](#), [1162](#).
- goto**: [35](#), [81](#).
- gr*: [128](#), [131](#), [132](#), [153](#).
- group_code*: [291](#), [293](#), [296](#), [815](#), [1312](#), [1676](#).
- group_trace*: [296](#), [304](#), [1659](#).
- group_warning*: [304](#), [1771](#).
- groupref*: [1634](#).
- grp_stack*: [304](#), [350](#), [353](#), [384](#), [1770](#), [1771](#), [1774](#).
- gsa_def*: [1836](#), [1837](#).
- gsa_w_def*: [1836](#), [1837](#).
- gubed**: [7](#).
- Guibas, Leonidas Ioannis: [2](#).
- g1*: [1374](#), [1379](#).
- g2*: [1374](#), [1379](#), [1381](#), [1634](#).
- h*: [222](#), [278](#), [281](#), [821](#), [842](#), [912](#), [1104](#), [1109](#), [1119](#), [1123](#), [1128](#), [1141](#), [1145](#), [1152](#), [1169](#), [1262](#), [1267](#), [1299](#), [1730](#), [1796](#).
- h_offset*: [265](#), [644](#), [645](#), [669](#), [755](#).
- `\hoffset` primitive: [266](#).
- h_offset_code*: [265](#), [266](#).
- ha*: [1067](#), [1071](#), [1075](#), [1078](#), [1087](#).
- half*: [100](#), [880](#), [910](#), [911](#), [912](#), [919](#), [920](#), [923](#), [924](#), [1378](#).
- half_buf*: [621](#), [622](#), [623](#), [625](#), [626](#).
- half_error_line*: [11](#), [14](#), [333](#), [337](#), [338](#), [339](#).
- halfp*: [111](#), [116](#), [120](#), [125](#).
- halfword*: [108](#), [128](#), [131](#), [133](#), [148](#), [286](#), [299](#), [301](#), [302](#), [303](#), [319](#), [320](#), [322](#), [355](#), [363](#), [388](#), [415](#), [439](#), [490](#), [499](#), [508](#), [575](#), [586](#), [604](#), [705](#), [706](#), [855](#), [965](#), [974](#), [995](#), [1003](#), [1004](#), [1007](#), [1021](#), [1046](#), [1051](#), [1067](#), [1076](#), [1081](#), [1082](#), [1152](#), [1207](#), [1255](#), [1277](#),

- 1387, 1419, 1442, 1464, 1625, 1653, 1680, 1720, 1735, 1811, 1816, 1819, 1836, 1837.
- halign*: [226](#), [287](#), [288](#), [1270](#), [1306](#).
- `\halign` primitive: [287](#).
- handle_right_brace*: [1243](#), [1244](#).
- hang_after*: [254](#), [258](#), [1021](#), [1023](#), [1246](#), [1325](#).
- `\hangafter` primitive: [256](#).
- hang_after_code*: [254](#), [255](#), [256](#), [1246](#).
- hang_indent*: [265](#), [1021](#), [1022](#), [1023](#), [1246](#), [1325](#).
- `\hangindent` primitive: [266](#).
- hang_indent_code*: [265](#), [266](#), [1246](#).
- hanging indentation: [1021](#).
- hasfmentry*: [799](#).
- hash*: [252](#), [274](#), [276](#), [278](#), [279](#), [281](#), [1494](#), [1495](#).
- hash_base*: [238](#), [240](#), [274](#), [276](#), [278](#), [284](#), [285](#), [394](#), [395](#), [527](#), [706](#), [1221](#), [1433](#), [1490](#), [1494](#), [1495](#).
- hash_brace*: [499](#), [502](#).
- hash_is_full*: [274](#), [279](#).
- hash_prime*: [12](#), [14](#), [278](#), [280](#), [1483](#), [1484](#).
- hash_size*: [12](#), [14](#), [240](#), [279](#), [280](#), [1512](#).
- hash_used*: [274](#), [277](#), [279](#), [1494](#), [1495](#).
- hb*: [1067](#), [1072](#), [1073](#), [1075](#), [1078](#).
- hbadness*: [254](#), [834](#), [840](#), [841](#).
- `\hbadness` primitive: [256](#).
- hbadness_code*: [254](#), [255](#), [256](#).
- `\hbox` primitive: [1247](#).
- hbox_group*: [291](#), [296](#), [1259](#), [1261](#), [1658](#), [1676](#).
- hc*: [1067](#), [1068](#), [1071](#), [1072](#), [1073](#), [1075](#), [1076](#), [1094](#), [1095](#), [1098](#), [1105](#), [1106](#), [1109](#), [1112](#), [1114](#), [1135](#), [1137](#), [1138](#), [1140](#), [1855](#).
- hchar*: [1080](#), [1081](#), [1083](#), [1084](#).
- hd*: [821](#), [826](#), [880](#), [882](#), [883](#), [886](#).
- head*: [230](#), [231](#), [233](#), [234](#), [235](#), [450](#), [892](#), [950](#), [970](#), [973](#), [979](#), [986](#), [988](#), [990](#), [1201](#), [1230](#), [1256](#), [1262](#), [1267](#), [1272](#), [1276](#), [1281](#), [1289](#), [1295](#), [1297](#), [1321](#), [1335](#), [1344](#), [1352](#), [1357](#), [1360](#), [1361](#), [1363](#), [1367](#).
- head_field*: [230](#), [231](#), [236](#).
- head_for_vmode*: [1270](#), [1271](#).
- head_tab*: [693](#), [695](#), [696](#), [697](#), [698](#), [789](#), [790](#), [795](#), [796](#), [797](#), [798](#), [799](#), [800](#), [801](#), [1502](#), [1503](#), [1543](#), [1597](#).
- head_tab_max*: [695](#), [696](#), [697](#).
- header*: [568](#).
- Hedrick, Charles Locke: [3](#).
- height*: [153](#), [154](#), [156](#), [157](#), [158](#), [202](#), [205](#), [206](#), [489](#), [498](#), [580](#), [644](#), [650](#), [652](#), [654](#), [657](#), [659](#), [660](#), [663](#), [665](#), [668](#), [669](#), [732](#), [734](#), [736](#), [738](#), [739](#), [741](#), [742](#), [745](#), [746](#), [752](#), [755](#), [821](#), [825](#), [830](#), [844](#), [846](#), [853](#), [878](#), [880](#), [883](#), [885](#), [887](#), [901](#), [904](#), [909](#), [910](#), [911](#), [912](#), [913](#), [916](#), [919](#), [920](#), [921](#), [923](#), [924](#), [925](#), [930](#), [931](#), [933](#), [942](#), [943](#), [970](#), [975](#), [978](#), [980](#), [981](#), [983](#), [984](#), [985](#), [1003](#), [1063](#), [1144](#), [1148](#), [1156](#), [1161](#), [1176](#), [1177](#), [1183](#), [1184](#), [1185](#), [1196](#), [1263](#), [1276](#), [1546](#), [1550](#), [1554](#), [1563](#), [1627](#), [1634](#), [1636](#), [1742](#).
- height*: [489](#).
- height_base*: [576](#), [578](#), [580](#), [592](#), [598](#), [705](#), [706](#), [1498](#), [1499](#).
- height_depth*: [580](#), [673](#), [826](#), [882](#), [883](#), [886](#), [1301](#), [1668](#).
- height_index*: [569](#), [580](#).
- height_offset*: [153](#), [442](#), [443](#), [943](#), [1423](#).
- height_plus_depth*: [886](#), [888](#).
- held over for next output: [1161](#).
- help_line*: [79](#), [89](#), [90](#), [358](#), [1282](#), [1388](#), [1389](#).
- help_ptr*: [79](#), [80](#), [89](#), [90](#).
- help0*: [79](#), [1428](#), [1469](#).
- help1*: [79](#), [93](#), [95](#), [310](#), [434](#), [454](#), [480](#), [512](#), [526](#), [529](#), [536](#), [1135](#), [1136](#), [1137](#), [1138](#), [1242](#), [1256](#), [1275](#), [1297](#), [1308](#), [1311](#), [1335](#), [1353](#), [1368](#), [1388](#), [1389](#), [1408](#), [1413](#), [1419](#), [1420](#), [1434](#), [1459](#), [1480](#), [1653](#), [1762](#), [1766](#), [1781](#).
- help2*: [72](#), [79](#), [88](#), [89](#), [94](#), [95](#), [121](#), [310](#), [368](#), [399](#), [459](#), [460](#), [461](#), [462](#), [463](#), [468](#), [471](#), [486](#), [497](#), [501](#), [502](#), [604](#), [606](#), [669](#), [683](#), [1111](#), [1112](#), [1153](#), [1190](#), [1202](#), [1223](#), [1244](#), [1256](#), [1258](#), [1271](#), [1282](#), [1296](#), [1305](#), [1342](#), [1373](#), [1383](#), [1401](#), [1412](#), [1417](#), [1435](#), [1537](#), [1616](#), [1693](#), [1779](#), [1808](#).
- help3*: [72](#), [79](#), [98](#), [358](#), [422](#), [441](#), [472](#), [505](#), [950](#), [957](#), [958](#), [966](#), [1168](#), [1184](#), [1199](#), [1203](#), [1254](#), [1260](#), [1286](#), [1303](#), [1359](#), [1371](#), [1469](#), [1537](#).
- help4*: [79](#), [89](#), [360](#), [424](#), [429](#), [444](#), [482](#), [593](#), [897](#), [1151](#), [1179](#), [1226](#), [1459](#).
- help5*: [79](#), [396](#), [587](#), [1000](#), [1240](#), [1245](#), [1304](#), [1391](#), [1469](#).
- help6*: [79](#), [421](#), [485](#), [1304](#), [1337](#).
- Here is how much...: [1512](#).
- hex_dig1*: [1816](#).
- hex_dig2*: [1816](#).
- hex_dig3*: [1816](#).
- hex_dig4*: [1816](#), [1818](#), [1819](#).
- hex_to_cur_chr*: [374](#), [377](#).
- hex_token*: [464](#), [470](#).
- hf*: [1067](#), [1071](#), [1072](#), [1073](#), [1078](#), [1083](#), [1084](#), [1085](#), [1086](#), [1090](#), [1091](#).
- `\hfil` primitive: [1234](#).
- `\hfilneg` primitive: [1234](#).
- `\hfill` primitive: [1234](#).
- hfuzz*: [265](#), [840](#).
- `\hfuzz` primitive: [266](#).
- hfuzz_code*: [265](#), [266](#).
- hh*: [128](#), [131](#), [132](#), [136](#), [151](#), [200](#), [231](#), [237](#), [239](#), [275](#), [290](#), [860](#), [916](#), [1339](#), [1341](#), [1357](#), [1362](#), [1481](#), [1482](#), [1814](#).
- hi*: [130](#), [250](#), [1408](#), [1751](#).

- hi_mem_min*: [134](#), [136](#), [138](#), [143](#), [144](#), [152](#), [182](#),
[183](#), [185](#), [186](#), [189](#), [190](#), [194](#), [315](#), [667](#), [1487](#),
[1488](#), [1512](#).
hi_mem_stat_min: [180](#), [182](#), [1488](#).
hi_mem_stat_usage: [180](#), [182](#).
history: [76](#), [77](#), [82](#), [93](#), [95](#), [263](#), [686](#), [1510](#), [1511](#),
[1513](#), [1771](#), [1773](#), [1774](#).
hlist_node: [153](#), [154](#), [155](#), [156](#), [166](#), [177](#), [193](#), [201](#),
[202](#), [220](#), [224](#), [497](#), [531](#), [643](#), [646](#), [647](#), [650](#), [659](#),
[729](#), [732](#), [741](#), [814](#), [821](#), [823](#), [843](#), [855](#), [981](#), [984](#),
[988](#), [1003](#), [1015](#), [1016](#), [1040](#), [1044](#), [1045](#), [1143](#),
[1148](#), [1168](#), [1175](#), [1250](#), [1256](#), [1263](#), [1286](#), [1323](#),
[1379](#), [1632](#), [1633](#), [1634](#), [1701](#), [1722](#), [1730](#).
hlist_out: [619](#), [642](#), [643](#), [646](#), [647](#), [648](#), [651](#),
[656](#), [657](#), [660](#), [665](#), [666](#), [668](#), [727](#), [729](#), [867](#),
[1617](#), [1696](#), [1723](#).
hlist_stack: [173](#), [819](#), [1003](#).
hlist_stack_level: [819](#), [1003](#).
hlp1: [79](#).
hlp2: [79](#).
hlp3: [79](#).
hlp4: [79](#).
hlp5: [79](#).
hlp6: [79](#).
hmode: [229](#), [236](#), [442](#), [527](#), [960](#), [961](#), [970](#), [973](#),
[1205](#), [1221](#), [1222](#), [1224](#), [1232](#), [1233](#), [1247](#), [1249](#),
[1252](#), [1255](#), [1259](#), [1262](#), [1267](#), [1268](#), [1269](#), [1270](#),
[1272](#), [1273](#), [1285](#), [1286](#), [1288](#), [1292](#), [1293](#), [1295](#),
[1298](#), [1306](#), [1313](#), [1376](#), [1419](#), [1622](#), [1676](#).
hmove: [226](#), [1224](#), [1247](#), [1248](#), [1249](#), [1678](#).
hn: [1067](#), [1072](#), [1073](#), [1074](#), [1077](#), [1087](#), [1088](#),
[1090](#), [1091](#), [1092](#), [1094](#), [1098](#), [1105](#), [1106](#).
ho: [130](#), [253](#), [440](#), [1327](#), [1330](#), [1753](#), [1754](#).
hold_head: [180](#), [328](#), [953](#), [957](#), [958](#), [968](#), [982](#), [1080](#),
[1081](#), [1088](#), [1089](#), [1090](#), [1091](#), [1092](#), [1189](#), [1192](#).
holding_inserts: [254](#), [1189](#).
\holdinginserts primitive: [256](#).
holding_inserts_code: [254](#), [255](#), [256](#).
hpack: [180](#), [254](#), [814](#), [815](#), [816](#), [817](#), [821](#), [832](#), [835](#),
[883](#), [889](#), [894](#), [901](#), [911](#), [922](#), [928](#), [930](#), [970](#),
[973](#), [978](#), [980](#), [1064](#), [1238](#), [1262](#), [1301](#), [1370](#),
[1375](#), [1377](#), [1380](#), [1702](#), [1733](#), [1743](#).
hrule: [226](#), [287](#), [288](#), [489](#), [1222](#), [1232](#), [1260](#),
[1270](#), [1271](#).
\hrule primitive: [287](#).
hsize: [265](#), [1021](#), [1022](#), [1023](#), [1230](#), [1325](#).
\hsize primitive: [266](#).
hsize_code: [265](#), [266](#).
hskip: [226](#), [1233](#), [1234](#), [1235](#), [1254](#), [1266](#).
\hskip primitive: [1234](#).
\hss primitive: [1234](#).
\ht primitive: [442](#).
hu: [1067](#), [1068](#), [1072](#), [1073](#), [1076](#), [1078](#), [1080](#),
[1082](#), [1083](#), [1085](#), [1086](#), [1087](#), [1090](#), [1091](#).
Huge page...: [669](#).
hyf: [1075](#), [1077](#), [1080](#), [1083](#), [1084](#), [1088](#), [1089](#),
[1094](#), [1095](#), [1098](#), [1099](#), [1107](#), [1135](#), [1136](#),
[1137](#), [1138](#), [1140](#).
hyf_bchar: [1067](#), [1072](#), [1073](#), [1078](#).
hyf_char: [1067](#), [1071](#), [1088](#), [1090](#).
hyf_distance: [1095](#), [1096](#), [1097](#), [1099](#), [1118](#), [1119](#),
[1120](#), [1500](#), [1501](#).
hyf_next: [1095](#), [1096](#), [1099](#), [1118](#), [1119](#), [1120](#),
[1500](#), [1501](#).
hyf_node: [1087](#), [1090](#).
hyf_num: [1095](#), [1096](#), [1099](#), [1118](#), [1119](#), [1120](#),
[1500](#), [1501](#).
hyph_codes: [1851](#), [1855](#).
hyph_count: [1101](#), [1103](#), [1115](#), [1500](#), [1501](#), [1512](#).
hyph_data: [227](#), [1386](#), [1426](#), [1427](#), [1428](#).
hyph_index: [1109](#), [1853](#), [1855](#).
hyph_list: [1101](#), [1103](#), [1104](#), [1107](#), [1108](#), [1109](#),
[1115](#), [1116](#), [1500](#), [1501](#).
hyph_pointer: [1100](#), [1101](#), [1102](#), [1104](#), [1109](#).
hyph_root: [1127](#), [1133](#), [1141](#), [1851](#), [1854](#).
hyph_size: [12](#), [1100](#), [1103](#), [1105](#), [1108](#), [1114](#), [1115](#),
[1483](#), [1484](#), [1500](#), [1501](#), [1512](#).
hyph_start: [1500](#), [1501](#), [1851](#), [1854](#), [1855](#).
hyph_word: [1101](#), [1103](#), [1104](#), [1106](#), [1109](#), [1115](#),
[1116](#), [1500](#), [1501](#).
hyphen_char: [173](#), [452](#), [575](#), [578](#), [603](#), [705](#), [706](#),
[1066](#), [1071](#), [1210](#), [1293](#), [1429](#), [1498](#), [1499](#).
\hyphenchar primitive: [1430](#).
hyphen_passed: [1080](#), [1081](#), [1084](#), [1088](#), [1089](#).
hyphen_penalty: [163](#), [254](#), [1043](#).
\hyphenpenalty primitive: [256](#).
hyphen_penalty_code: [254](#), [255](#), [256](#).
hyphenate: [1069](#), [1070](#).
hyphenated: [993](#), [994](#), [1003](#), [1020](#), [1033](#), [1043](#),
[1047](#).
Hyphenation trie...: [1500](#).
\hyphenation primitive: [1426](#).
i: [19](#), [125](#), [337](#), [439](#), [496](#), [604](#), [614](#), [699](#), [702](#), [705](#),
[706](#), [712](#), [725](#), [727](#), [729](#), [750](#), [793](#), [821](#), [912](#),
[923](#), [1076](#), [1299](#), [1526](#), [1676](#), [1771](#), [1773](#), [1774](#),
[1812](#), [1816](#), [1818](#), [1822](#), [1834](#).
I can't find file x: [556](#).
I can't find PLAIN...: [550](#).
I can't go on...: [95](#).
I can't read TEX.POOL: [51](#).
I can't write on file x: [556](#).
id: [1562](#).
id_byte: [614](#), [645](#), [670](#).
id_lookup: [278](#), [286](#), [378](#), [400](#), [1765](#).

- ident_val*: [436](#), [441](#), [491](#), [492](#).
- `\ifcase` primitive: [513](#).
- if_case_code*: [513](#), [514](#), [527](#), [1762](#).
- if_cat_code*: [513](#), [514](#), [527](#).
- `\ifcat` primitive: [513](#).
- `\if` primitive: [513](#).
- if_char_code*: [513](#), [527](#), [532](#).
- if_code*: [515](#), [521](#), [536](#).
- if_cs_code*: [1759](#), [1761](#), [1764](#).
- `\ifcsname` primitive: [1759](#).
- if_cur_ptr_is_null_then_return_or_goto*: [1816](#).
- if_def_code*: [1759](#), [1761](#), [1763](#).
- `\ifdefined` primitive: [1759](#).
- `\ifdim` primitive: [513](#).
- if_dim_code*: [513](#), [514](#), [527](#).
- `\ifeof` primitive: [513](#).
- if_eof_code*: [513](#), [514](#), [527](#).
- `\iffalse` primitive: [513](#).
- if_false_code*: [513](#), [514](#), [527](#).
- `\iffontchar` primitive: [1759](#).
- if_font_char_code*: [1759](#), [1761](#), [1766](#).
- `\ifhbox` primitive: [513](#).
- if_hbox_code*: [513](#), [514](#), [527](#), [531](#).
- `\ifhmode` primitive: [513](#).
- if_hmode_code*: [513](#), [514](#), [527](#).
- `\ifincsname` primitive: [1759](#).
- if_in_csname_code*: [1759](#), [1761](#), [1766](#).
- `\ifinner` primitive: [513](#).
- if_inner_code*: [513](#), [514](#), [527](#).
- `\ifnum` primitive: [513](#).
- if_int_code*: [513](#), [514](#), [527](#), [529](#).
- if_limit*: [515](#), [516](#), [521](#), [522](#), [523](#), [524](#), [536](#), [1665](#), [1688](#), [1774](#).
- if_line*: [321](#), [515](#), [516](#), [521](#), [522](#), [1513](#), [1688](#), [1773](#), [1774](#).
- if_line_field*: [515](#), [521](#), [522](#), [1513](#), [1688](#), [1774](#).
- `\ifmmode` primitive: [513](#).
- if_mmode_code*: [513](#), [514](#), [527](#).
- if_node_size*: [515](#), [521](#), [522](#), [1513](#).
- `\ifodd` primitive: [513](#).
- if_odd_code*: [513](#), [514](#), [527](#).
- `\ifpdfabsdim` primitive: [1759](#).
- if_pdfabs_dim_code*: [1759](#), [1761](#), [1766](#).
- `\ifpdfabsnum` primitive: [1759](#).
- if_pdfabs_num_code*: [1759](#), [1761](#), [1766](#).
- if_pdfprimitive*: [1759](#).
- `\ifpdfprimitive` primitive: [513](#).
- if_pdfprimitive_code*: [513](#), [514](#), [527](#).
- if_stack*: [350](#), [353](#), [384](#), [522](#), [1770](#), [1773](#), [1774](#).
- if_test*: [228](#), [321](#), [358](#), [388](#), [391](#), [513](#), [514](#), [520](#), [524](#), [529](#), [1513](#), [1688](#), [1759](#), [1762](#), [1766](#), [1773](#), [1774](#).
- `\iftrue` primitive: [513](#).
- if_true_code*: [513](#), [514](#), [527](#).
- `\ifvbox` primitive: [513](#).
- if_vbox_code*: [513](#), [514](#), [527](#).
- `\ifvmode` primitive: [513](#).
- if_vmode_code*: [513](#), [514](#), [527](#).
- `\ifvoid` primitive: [513](#).
- if_void_code*: [513](#), [514](#), [527](#), [531](#).
- if_warning*: [522](#), [1773](#).
- `\ifx` primitive: [513](#).
- ifx_code*: [513](#), [514](#), [527](#).
- ignore*: [225](#), [250](#), [354](#), [367](#).
- ignore_depth*: [230](#), [233](#), [1062](#).
- ignore_spaces*: [226](#), [277](#), [287](#), [288](#), [394](#), [439](#), [1221](#).
- `\ignorespaces` primitive: [287](#).
- Illegal magnification...: [310](#), [1434](#).
- Illegal math `\disc`...: [1296](#).
- Illegal parameter number...: [505](#).
- Illegal unit of measure: [480](#), [482](#), [485](#).
- image*: [1550](#), [1634](#).
- image_colordepth*: [1550](#).
- image_height*: [498](#), [1550](#), [1634](#).
- image_orig_x*: [1625](#).
- image_orig_y*: [1625](#).
- image_pages*: [1550](#).
- image_rotate*: [1550](#), [1634](#).
- image_width*: [498](#), [1550](#), [1634](#).
- image_x_res*: [1550](#).
- image_y_res*: [1550](#).
- img_h*: [1634](#).
- img_w*: [1634](#).
- `\immediate` primitive: [1522](#).
- immediate_code*: [1522](#), [1524](#), [1526](#).
- IMPOSSIBLE: [284](#).
- Improper `\beginL`: [1700](#).
- Improper `\beginR`: [1700](#).
- Improper `\endL`: [1700](#).
- Improper `\endR`: [1700](#).
- Improper `\halign`...: [950](#).
- Improper `\hyphenation`...: [1111](#).
- Improper `\prevdepth`: [444](#).
- Improper `\setbox`: [1417](#).
- Improper `\spacefactor`: [444](#).
- Improper ‘at’ size...: [1435](#).
- Improper alphabetic constant: [468](#).
- Improper discretionary list: [1297](#).
- in*: [484](#).
- in_open*: [304](#), [326](#), [335](#), [350](#), [351](#), [353](#), [384](#), [522](#), [1771](#), [1773](#), [1774](#).
- in_state_record*: [322](#), [323](#).
- in_stream*: [226](#), [1448](#), [1449](#), [1450](#).
- inaccessible: [1392](#).
- Incompatible glue units: [434](#).

- Incompatible list...**: 1286.
- Incompatible magnification**: 310.
- incomplete_noad*: 230, [231](#), 892, 950, 1312, 1354, 1357, 1358, 1360, 1361.
- Incomplete \if...**: 358.
- incr*: [16](#), [31](#), [37](#), [42](#), [43](#), [45](#), [46](#), [53](#), [58](#), [59](#), [60](#), [65](#), [67](#), [70](#), [71](#), [82](#), [90](#), [98](#), [113](#), [138](#), [140](#), [170](#), [171](#), [188](#), [200](#), [221](#), [234](#), [279](#), [296](#), [298](#), [302](#), [316](#), [321](#), [333](#), [334](#), [343](#), [347](#), [348](#), [350](#), [365](#), [369](#), [374](#), [376](#), [377](#), [378](#), [379](#), [382](#), [384](#), [400](#), [418](#), [421](#), [423](#), [425](#), [426](#), [429](#), [433](#), [468](#), [478](#), [480](#), [490](#), [501](#), [502](#), [503](#), [520](#), [543](#), [545](#), [550](#), [557](#), [563](#), [607](#), [625](#), [647](#), [657](#), [668](#), [670](#), [674](#), [680](#), [686](#), [689](#), [693](#), [698](#), [699](#), [702](#), [705](#), [706](#), [715](#), [719](#), [720](#), [725](#), [726](#), [727](#), [729](#), [738](#), [749](#), [751](#), [788](#), [793](#), [800](#), [801](#), [803](#), [815](#), [821](#), [888](#), [972](#), [1019](#), [1051](#), [1072](#), [1073](#), [1085](#), [1086](#), [1089](#), [1090](#), [1098](#), [1105](#), [1106](#), [1112](#), [1114](#), [1115](#), [1116](#), [1119](#), [1129](#), [1131](#), [1137](#), [1138](#), [1139](#), [1161](#), [1197](#), [1200](#), [1210](#), [1214](#), [1245](#), [1293](#), [1295](#), [1297](#), [1303](#), [1318](#), [1329](#), [1348](#), [1350](#), [1491](#), [1492](#), [1494](#), [1515](#), [1534](#), [1535](#), [1542](#), [1546](#), [1550](#), [1560](#), [1585](#), [1632](#), [1634](#), [1645](#), [1665](#), [1676](#), [1680](#), [1688](#), [1708](#), [1714](#), [1725](#), [1736](#), [1751](#), [1752](#), [1758](#), [1765](#), [1779](#), [1794](#), [1797](#), [1816](#), [1818](#), [1834](#).
- \indent primitive**: [1264](#).
- indent_in_hmode*: [1264](#), [1268](#), [1269](#).
- indented*: [1267](#).
- index*: [322](#), [324](#), [325](#), [326](#), [329](#), [335](#), [350](#), [351](#), [353](#), [384](#).
- index_field*: [322](#), [324](#), [1307](#), [1772](#).
- index_node_size*: [1812](#), [1818](#), [1822](#).
- inf*: [473](#), [474](#), [479](#).
- inf_bad*: [108](#), [175](#), [1025](#), [1026](#), [1027](#), [1030](#), [1037](#), [1149](#), [1180](#), [1192](#), [1844](#).
- inf_dest_names_size*: [695](#), [697](#).
- inf_obj_tab_size*: [695](#), [697](#).
- inf_pdf_mem_size*: [675](#), [677](#).
- inf_pdf_os_buf_size*: [679](#), [681](#).
- inf_penalty*: [175](#), [935](#), [941](#), [990](#), [1003](#), [1005](#), [1149](#), [1180](#), [1188](#), [1379](#), [1381](#).
- inf_pk_dpi*: [695](#).
- Infinite glue shrinkage...**: [1000](#), [1151](#), [1179](#), [1184](#).
- infinity*: [471](#), [1787](#), [1789](#), [1795](#).
- info*: [136](#), [142](#), [144](#), [158](#), [159](#), [173](#), [182](#), [190](#), [218](#), [251](#), [297](#), [313](#), [315](#), [347](#), [348](#), [359](#), [361](#), [379](#), [380](#), [393](#), [394](#), [397](#), [400](#), [415](#), [417](#), [418](#), [419](#), [420](#), [423](#), [426](#), [449](#), [478](#), [492](#), [504](#), [534](#), [632](#), [635](#), [636](#), [637](#), [638](#), [639](#), [640](#), [641](#), [642](#), [693](#), [695](#), [700](#), [766](#), [767](#), [771](#), [773](#), [775](#), [779](#), [781](#), [782](#), [783](#), [784](#), [786](#), [855](#), [863](#), [866](#), [867](#), [872](#), [894](#), [908](#), [909](#), [910](#), [911](#), [912](#), [916](#), [923](#), [928](#), [942](#), [943](#), [946](#), [953](#), [957](#), [958](#), [964](#), [967](#), [968](#), [971](#), [972](#), [975](#), [977](#), [995](#), [1021](#), [1022](#), [1100](#), [1107](#), [1113](#), [1156](#), [1241](#), [1252](#), [1269](#), [1325](#), [1327](#), [1344](#), [1357](#), [1361](#), [1362](#), [1367](#), [1394](#), [1402](#), [1424](#), [1425](#), [1465](#), [1471](#), [1488](#), [1517](#), [1519](#), [1615](#), [1633](#), [1634](#), [1671](#), [1702](#), [1704](#), [1705](#), [1706](#), [1708](#), [1709](#), [1714](#), [1715](#), [1720](#), [1725](#), [1728](#), [1734](#), [1736](#), [1747](#), [1751](#), [1753](#), [1754](#), [1765](#), [1769](#), [1812](#), [1816](#), [1817](#), [1821](#), [1822](#).
- init**: [8](#), [47](#), [50](#), [149](#), [286](#), [1066](#), [1109](#), [1117](#), [1118](#), [1122](#), [1125](#), [1428](#), [1478](#), [1501](#), [1510](#), [1513](#), [1514](#), [1645](#), [1828](#).
- init_align*: [947](#), [948](#), [1306](#).
- init_col*: [947](#), [959](#), [962](#), [965](#).
- init_cur_lang*: [990](#), [1066](#), [1067](#).
- init_font_base*: [705](#).
- init_hyph*: [990](#), [1066](#), [1067](#).
- init_lft*: [1075](#), [1078](#), [1080](#), [1083](#).
- init_lig*: [1075](#), [1078](#), [1080](#), [1083](#).
- init_list*: [1075](#), [1078](#), [1080](#), [1083](#).
- init_math*: [1313](#), [1314](#), [1702](#).
- init_pdf_output*: [687](#), [688](#), [750](#).
- init_pool_ptr*: [39](#), [42](#), [1486](#), [1510](#), [1512](#).
- init_prim*: [1510](#), [1514](#).
- init_r_hyph*: [990](#), [1066](#), [1067](#).
- init_randoms*: [125](#), [1515](#), [1583](#).
- init_row*: [947](#), [959](#), [960](#).
- init_span*: [947](#), [960](#), [961](#), [965](#).
- init_start_time*: [1582](#).
- init_str_ptr*: [39](#), [43](#), [543](#), [1486](#), [1510](#), [1512](#).
- init_terminal*: [37](#), [353](#).
- init_trie*: [1066](#), [1141](#), [1500](#).
- INITEX**: [8](#), [11](#), [12](#), [47](#), [50](#), [134](#), [1475](#), [1509](#), [1822](#), [1828](#).
- initialize*: [4](#), [1510](#), [1515](#).
- inner loop**: [31](#), [112](#), [113](#), [116](#), [130](#), [138](#), [139](#), [140](#), [141](#), [143](#), [145](#), [146](#), [148](#), [220](#), [346](#), [347](#), [363](#), [364](#), [365](#), [379](#), [387](#), [406](#), [425](#), [433](#), [580](#), [624](#), [638](#), [648](#), [823](#), [826](#), [827](#), [1006](#), [1009](#), [1025](#), [1026](#), [1041](#), [1205](#), [1209](#), [1210](#), [1211](#), [1214](#), [1217](#).
- inner_noad*: [856](#), [857](#), [864](#), [870](#), [872](#), [907](#), [935](#), [938](#), [1332](#), [1333](#), [1367](#).
- input*: [228](#), [388](#), [391](#), [402](#), [403](#), [1744](#).
- \input primitive**: [402](#).
- input_file*: [326](#).
- \inputlineno primitive**: [442](#).
- input_line_no_code*: [442](#), [443](#), [450](#).
- input_ln*: [30](#), [31](#), [37](#), [58](#), [71](#), [384](#), [511](#), [512](#), [564](#).
- input_ptr*: [323](#), [333](#), [334](#), [343](#), [344](#), [352](#), [353](#), [382](#), [560](#), [1307](#), [1513](#), [1771](#), [1773](#).
- input_stack*: [84](#), [85](#), [323](#), [333](#), [343](#), [344](#), [560](#), [1307](#), [1771](#), [1772](#), [1773](#).
- ins_disc*: [1207](#), [1208](#), [1210](#).

- ins_error*: [349](#), [358](#), [421](#), [1223](#), [1303](#), [1308](#), [1391](#).
- ins_list*: [345](#), [361](#), [493](#), [496](#), [497](#), [1240](#), [1615](#).
- ins_node*: [158](#), [166](#), [193](#), [201](#), [220](#), [224](#), [817](#), [823](#), [904](#), [935](#), [1003](#), [1040](#), [1074](#), [1143](#), [1148](#), [1156](#), [1161](#), [1175](#), [1189](#), [1276](#).
- ins_node_size*: [158](#), [220](#), [224](#), [1197](#), [1276](#).
- ins_ptr*: [158](#), [206](#), [220](#), [224](#), [1185](#), [1195](#), [1196](#), [1276](#).
- ins_the_toks*: [388](#), [391](#), [493](#).
- insert*: [226](#), [287](#), [288](#), [1273](#).
- insert*>: [87](#).
- \insert* primitive: [287](#).
- insert_dollar_sign*: [1221](#), [1223](#).
- insert_group*: [291](#), [1244](#), [1275](#), [1276](#), [1658](#), [1676](#).
- insert_penalties*: [445](#), [1157](#), [1165](#), [1180](#), [1183](#), [1185](#), [1189](#), [1197](#), [1201](#), [1418](#), [1422](#).
- \insertpenalties* primitive: [442](#).
- insert_relax*: [404](#), [405](#), [536](#).
- insert_token*: [290](#), [302](#), [304](#).
- inserted*: [329](#), [336](#), [345](#), [346](#), [349](#), [405](#), [1271](#).
- inserting*: [1156](#), [1184](#).
- Insertions can only...*: [1168](#).
- inserts_only*: [1155](#), [1162](#), [1183](#).
- int*: [128](#), [131](#), [132](#), [158](#), [160](#), [175](#), [204](#), [231](#), [237](#), [254](#), [258](#), [260](#), [296](#), [300](#), [301](#), [439](#), [440](#), [515](#), [632](#), [695](#), [710](#), [899](#), [943](#), [946](#), [993](#), [1413](#), [1424](#), [1481](#), [1482](#), [1484](#), [1492](#), [1646](#), [1785](#), [1817](#).
- int_base*: [238](#), [248](#), [250](#), [254](#), [256](#), [257](#), [258](#), [260](#), [270](#), [271](#), [272](#), [290](#), [305](#), [310](#), [1188](#), [1246](#), [1315](#), [1321](#), [1491](#), [1646](#), [1654](#).
- int_error*: [91](#), [310](#), [459](#), [460](#), [461](#), [462](#), [463](#), [497](#), [683](#), [1419](#), [1420](#), [1434](#), [1693](#), [1808](#).
- int_par*: [254](#), [673](#).
- int_pars*: [254](#).
- int_val*: [436](#), [437](#), [439](#), [440](#), [442](#), [443](#), [444](#), [445](#), [448](#), [449](#), [450](#), [452](#), [453](#), [454](#), [455](#), [465](#), [466](#), [475](#), [487](#), [491](#), [497](#), [1400](#), [1412](#), [1413](#), [1414](#), [1416](#), [1487](#), [1488](#), [1535](#), [1775](#), [1776](#), [1777](#), [1780](#), [1782](#), [1787](#), [1789](#), [1792](#), [1795](#), [1812](#), [1813](#), [1815](#), [1820](#), [1829](#).
- integer*: [3](#), [13](#), [19](#), [45](#), [47](#), [54](#), [59](#), [60](#), [63](#), [66](#), [67](#), [69](#), [82](#), [91](#), [94](#), [96](#), [100](#), [101](#), [102](#), [105](#), [106](#), [107](#), [108](#), [109](#), [110](#), [112](#), [114](#), [117](#), [119](#), [122](#), [124](#), [125](#), [126](#), [127](#), [128](#), [131](#), [135](#), [143](#), [176](#), [181](#), [190](#), [191](#), [192](#), [194](#), [195](#), [196](#), [199](#), [200](#), [229](#), [230](#), [236](#), [243](#), [255](#), [264](#), [265](#), [274](#), [278](#), [281](#), [284](#), [286](#), [300](#), [301](#), [308](#), [314](#), [320](#), [321](#), [326](#), [330](#), [331](#), [333](#), [337](#), [388](#), [436](#), [439](#), [466](#), [474](#), [476](#), [496](#), [508](#), [515](#), [519](#), [520](#), [524](#), [544](#), [545](#), [549](#), [575](#), [576](#), [586](#), [597](#), [604](#), [605](#), [608](#), [619](#), [622](#), [627](#), [628](#), [634](#), [642](#), [643](#), [647](#), [657](#), [666](#), [673](#), [674](#), [676](#), [678](#), [680](#), [682](#), [686](#), [687](#), [689](#), [690](#), [691](#), [692](#), [693](#), [694](#), [696](#), [698](#), [700](#), [701](#), [702](#), [705](#), [706](#), [707](#), [708](#), [710](#), [712](#), [720](#), [725](#), [727](#), [750](#), [772](#), [774](#), [778](#), [793](#), [795](#), [815](#), [816](#), [819](#), [821](#), [835](#), [865](#), [868](#), [873](#), [880](#), [890](#), [891](#), [900](#), [912](#), [926](#), [938](#), [997](#), [1002](#), [1003](#), [1004](#), [1007](#), [1046](#), [1051](#), [1067](#), [1087](#), [1097](#), [1141](#), [1145](#), [1155](#), [1157](#), [1169](#), [1187](#), [1205](#), [1207](#), [1244](#), [1251](#), [1255](#), [1260](#), [1267](#), [1293](#), [1295](#), [1314](#), [1327](#), [1331](#), [1370](#), [1387](#), [1412](#), [1469](#), [1478](#), [1479](#), [1503](#), [1509](#), [1511](#), [1516](#), [1526](#), [1541](#), [1543](#), [1545](#), [1548](#), [1550](#), [1553](#), [1554](#), [1555](#), [1557](#), [1560](#), [1562](#), [1568](#), [1581](#), [1597](#), [1614](#), [1624](#), [1625](#), [1627](#), [1629](#), [1634](#), [1676](#), [1702](#), [1741](#), [1750](#), [1753](#), [1774](#), [1779](#), [1790](#), [1794](#), [1796](#), [1836](#), [1837](#).
- \interlinepenalties* primitive: [1861](#).
- inter_line_penalties_loc*: [248](#), [1246](#), [1861](#), [1862](#).
- inter_line_penalties_ptr*: [1065](#), [1246](#), [1861](#).
- inter_line_penalty*: [254](#), [1065](#).
- \interlinepenalty* primitive: [256](#).
- inter_line_penalty_code*: [254](#), [255](#), [256](#).
- interaction*: [71](#), [72](#), [73](#), [74](#), [75](#), [82](#), [83](#), [84](#), [86](#), [90](#), [92](#), [93](#), [98](#), [382](#), [385](#), [510](#), [556](#), [686](#), [1441](#), [1459](#), [1469](#), [1470](#), [1473](#), [1504](#), [1505](#), [1506](#), [1513](#), [1691](#).
- \interactionmode* primitive: [1689](#).
- internal_font_number*: [192](#), [574](#), [575](#), [576](#), [586](#), [604](#), [605](#), [608](#), [609](#), [629](#), [643](#), [673](#), [686](#), [690](#), [691](#), [692](#), [693](#), [705](#), [706](#), [710](#), [712](#), [720](#), [725](#), [819](#), [821](#), [880](#), [883](#), [885](#), [886](#), [889](#), [898](#), [912](#), [1004](#), [1036](#), [1067](#), [1207](#), [1289](#), [1299](#), [1314](#), [1387](#), [1433](#), [1585](#).
- interrupt*: [96](#), [97](#), [98](#), [1206](#).
- Interruption*: [98](#).
- interwoven alignment preambles...*: [346](#), [956](#), [963](#), [965](#), [1307](#).
- int0*: [694](#), [695](#), [1502](#), [1503](#).
- int1*: [694](#), [695](#), [1502](#), [1503](#).
- int2*: [694](#), [695](#), [1503](#).
- int3*: [694](#), [695](#), [1502](#), [1503](#).
- int4*: [694](#), [695](#), [1502](#), [1503](#).
- Invalid code*: [1408](#).
- Invalid negative color stack number*: [1537](#).
- invalid_char*: [225](#), [250](#), [366](#).
- invalid_code*: [22](#), [24](#), [250](#).
- is_char_node*: [152](#), [192](#), [201](#), [220](#), [223](#), [450](#), [498](#), [648](#), [658](#), [674](#), [705](#), [731](#), [740](#), [821](#), [823](#), [843](#), [889](#), [894](#), [895](#), [930](#), [979](#), [990](#), [1003](#), [1011](#), [1015](#), [1016](#), [1040](#), [1041](#), [1042](#), [1044](#), [1045](#), [1053](#), [1055](#), [1071](#), [1072](#), [1074](#), [1078](#), [1211](#), [1216](#), [1256](#), [1281](#), [1286](#), [1289](#), [1297](#), [1323](#), [1378](#), [1634](#), [1704](#), [1721](#), [1730](#), [1735](#).
- is_empty*: [142](#), [145](#), [187](#), [188](#).
- is_error*: [1535](#).
- is_hex*: [374](#), [377](#).
- is_hex_char*: [702](#).
- is_hex_string*: [702](#).
- is_in_cname*: [389](#), [390](#), [398](#), [1764](#), [1766](#).
- is_letterspaced_font*: [706](#).

- is_names*: [802](#), [803](#), [1511](#).
- is_obj_scheduled*: [695](#), [1627](#), [1632](#).
- is_obj_written*: [695](#), [773](#), [775](#), [779](#), [784](#), [810](#), [811](#), [812](#).
- is_pdf_image*: [498](#), [1550](#), [1634](#).
- is_png_image*: [1634](#).
- is_root*: [800](#), [801](#), [1511](#).
- is_running*: [156](#), [194](#), [652](#), [661](#), [730](#), [734](#), [739](#), [743](#), [980](#), [1550](#), [1627](#), [1632](#), [1634](#).
- is_shipping_page*: [750](#), [1627](#), [1632](#), [1634](#), [1637](#), [1638](#).
- is_unless*: [524](#).
- is_valid_char*: [604](#), [673](#), [705](#), [717](#), [726](#), [731](#).
- isscalable*: [690](#), [693](#).
- issue_message*: [1452](#), [1455](#).
- ital_corr*: [226](#), [287](#), [288](#), [1287](#), [1288](#).
- italic correction: [569](#).
- italic_base*: [576](#), [578](#), [580](#), [592](#), [598](#), [705](#), [706](#), [1498](#), [1499](#).
- italic_index*: [569](#).
- its_all_over*: [1221](#), [1230](#), [1513](#).
- i1*: [1535](#).
- i2*: [1535](#).
- j*: [45](#), [46](#), [59](#), [60](#), [69](#), [70](#), [125](#), [278](#), [281](#), [286](#), [337](#), [388](#), [496](#), [508](#), [545](#), [549](#), [550](#), [666](#), [686](#), [693](#), [749](#), [1068](#), [1076](#), [1081](#), [1109](#), [1141](#), [1314](#), [1387](#), [1478](#), [1479](#), [1526](#), [1614](#), [1617](#), [1653](#), [1676](#), [1738](#), [1741](#).
- j_random*: [110](#), [124](#), [126](#), [127](#).
- Japanese characters: [152](#), [612](#).
- Jensen, Kathleen: [10](#).
- jj*: [125](#).
- job aborted: [382](#).
- job aborted, file error...: [556](#).
- job_name*: [92](#), [497](#), [498](#), [553](#), [554](#), [555](#), [558](#), [560](#), [563](#), [684](#), [1433](#), [1506](#), [1513](#).
- `\jobname` primitive: [494](#).
- job_name_code*: [494](#), [496](#), [497](#), [498](#).
- jump_out*: [81](#), [82](#), [84](#), [93](#).
- just_box*: [988](#), [1063](#), [1064](#), [1324](#), [1731](#), [1737](#).
- just_copy*: [1730](#), [1731](#), [1735](#).
- just_open*: [506](#), [509](#), [1451](#).
- just_reverse*: [1734](#), [1735](#).
- j1*: [793](#), [1535](#).
- j2*: [793](#), [1535](#).
- k*: [45](#), [46](#), [47](#), [64](#), [65](#), [67](#), [69](#), [71](#), [102](#), [119](#), [124](#), [125](#), [181](#), [278](#), [281](#), [286](#), [363](#), [385](#), [433](#), [476](#), [490](#), [545](#), [549](#), [551](#), [556](#), [560](#), [586](#), [614](#), [624](#), [629](#), [634](#), [666](#), [686](#), [693](#), [702](#), [705](#), [706](#), [712](#), [821](#), [879](#), [1081](#), [1104](#), [1109](#), [1135](#), [1141](#), [1255](#), [1387](#), [1478](#), [1479](#), [1516](#), [1526](#), [1543](#), [1550](#), [1560](#), [1612](#), [1634](#), [1653](#), [1812](#).
- kern*: [226](#), [571](#), [1233](#), [1234](#), [1235](#).
- `\kern` primitive: [1234](#).
- kern_base*: [576](#), [578](#), [583](#), [592](#), [600](#), [603](#), [705](#), [706](#), [1498](#), [1499](#).
- kern_base_offset*: [583](#), [592](#), [600](#), [705](#).
- kern_break*: [1040](#).
- kern_flag*: [571](#), [821](#), [915](#), [927](#), [1084](#), [1216](#).
- kern_node*: [173](#), [174](#), [201](#), [220](#), [224](#), [450](#), [650](#), [659](#), [674](#), [705](#), [732](#), [741](#), [823](#), [843](#), [895](#), [904](#), [906](#), [935](#), [1003](#), [1011](#), [1015](#), [1016](#), [1030](#), [1040](#), [1042](#), [1044](#), [1045](#), [1053](#), [1055](#), [1071](#), [1072](#), [1074](#), [1143](#), [1147](#), [1148](#), [1151](#), [1171](#), [1172](#), [1175](#), [1179](#), [1282](#), [1283](#), [1284](#), [1297](#), [1323](#), [1634](#), [1696](#), [1708](#), [1714](#), [1722](#), [1725](#), [1730](#), [1736](#).
- kern_shrink*: [821](#), [823](#), [1013](#).
- kern_stretch*: [821](#), [823](#), [1013](#).
- kk*: [476](#), [478](#), [749](#).
- kn*: [705](#).
- `\knaccode` primitive: [1430](#).
- kn_ac_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- `\knbccode` primitive: [1430](#).
- kn_bc_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- `\knbscode` primitive: [1430](#).
- kn_bs_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- Knuth, Donald Ervin: [2](#), [86](#), [867](#), [987](#), [1066](#), [1100](#), [1172](#), [1330](#), [1615](#), [1676](#), [1697](#).
- kpse_init_prog*: [792](#).
- kpse_pk_format*: [792](#).
- kpse_set_program_enabled*: [792](#).
- kpse_src_compile*: [792](#).
- l*: [47](#), [127](#), [278](#), [281](#), [286](#), [298](#), [303](#), [314](#), [321](#), [337](#), [520](#), [523](#), [560](#), [628](#), [642](#), [821](#), [842](#), [1003](#), [1004](#), [1076](#), [1119](#), [1128](#), [1135](#), [1314](#), [1370](#), [1412](#), [1469](#), [1478](#), [1516](#), [1621](#), [1676](#), [1720](#), [1735](#), [1750](#), [1774](#), [1779](#), [1822](#).
- L_code*: [165](#), [193](#), [210](#), [1040](#), [1071](#), [1074](#), [1714](#), [1715](#), [1733](#), [1734](#).
- L_hyf*: [1066](#), [1067](#), [1069](#), [1074](#), [1077](#), [1098](#), [1606](#), [1607](#).
- language*: [254](#), [1109](#), [1209](#), [1621](#).
- `\language` primitive: [256](#).
- language_code*: [254](#), [255](#), [256](#).
- language_node*: [1519](#), [1600](#), [1601](#), [1602](#), [1606](#), [1607](#), [1617](#), [1621](#), [1622](#).
- large_attempt*: [880](#).
- large_char*: [857](#), [865](#), [871](#), [880](#), [1336](#).
- large_fam*: [857](#), [865](#), [871](#), [880](#), [1336](#).
- last*: [30](#), [31](#), [35](#), [36](#), [37](#), [71](#), [83](#), [87](#), [88](#), [353](#), [382](#), [385](#), [509](#), [550](#), [557](#), [1753](#).
- last_active*: [993](#), [994](#), [1006](#), [1009](#), [1018](#), [1028](#), [1034](#), [1035](#), [1037](#), [1038](#), [1039](#), [1047](#), [1048](#), [1049](#).
- last_attr*: [1597](#).

last_badness: [450](#), [816](#), [818](#), [821](#), [834](#), [838](#), [841](#),
[842](#), [848](#), [850](#), [852](#).
last_bop: [619](#), [620](#), [668](#), [670](#).
\lastbox primitive: [1247](#).
last_box_code: [1247](#), [1248](#), [1255](#), [1513](#), [1856](#),
[1858](#), [1859](#).
last_glue: [450](#), [1157](#), [1166](#), [1171](#), [1192](#), [1282](#), [1513](#).
last_ins_ptr: [1156](#), [1180](#), [1183](#), [1193](#), [1195](#).
last_item: [226](#), [439](#), [442](#), [443](#), [1224](#), [1646](#), [1660](#),
[1663](#), [1666](#), [1669](#), [1775](#), [1798](#), [1802](#).
last_kern: [450](#), [1157](#), [1166](#), [1171](#).
\lastkern primitive: [442](#).
last_leftmost_char: [819](#), [820](#), [821](#), [1061](#).
last_line_fill: [990](#), [1839](#), [1840](#), [1850](#).
last_line_fit: [254](#), [1839](#), [1840](#), [1843](#).
\lastlinefit primitive: [1654](#).
last_line_fit_code: [254](#), [1654](#), [1656](#).
last_node_type: [450](#), [1157](#), [1166](#), [1171](#).
\lastnodetype primitive: [1646](#).
last_node_type_code: [442](#), [450](#), [1646](#), [1647](#).
last_nonblank: [31](#).
last_penalty: [450](#), [1157](#), [1166](#), [1171](#).
\lastpenalty primitive: [442](#).
last_pos: [1634](#).
last_rightmost_char: [819](#), [820](#), [821](#), [1055](#).
\lastskip primitive: [442](#).
last_special_line: [1021](#), [1022](#), [1023](#), [1024](#), [1064](#).
last_text_char: [19](#), [24](#).
last_thread: [739](#), [754](#), [1625](#), [1634](#).
last_tokens_string: [686](#), [708](#), [709](#), [1561](#), [1627](#).
lc: [821](#).
lc_code: [248](#), [250](#), [1066](#), [1137](#), [1851](#), [1853](#), [1854](#),
[1855](#).
\lccode primitive: [1406](#).
lc_code_base: [248](#), [253](#), [1406](#), [1407](#), [1462](#), [1463](#),
[1464](#).
leader_box: [647](#), [654](#), [656](#), [657](#), [663](#), [665](#), [729](#),
[736](#), [737](#), [738](#), [745](#), [746](#).
leader_flag: [1247](#), [1249](#), [1254](#), [1260](#), [1678](#).
leader_ht: [657](#), [663](#), [664](#), [665](#), [738](#), [745](#), [746](#).
leader_ptr: [167](#), [170](#), [171](#), [208](#), [220](#), [224](#), [654](#), [663](#),
[736](#), [745](#), [830](#), [845](#), [990](#), [1254](#), [1730](#).
leader_ship: [226](#), [1247](#), [1248](#), [1249](#), [1678](#).
leader_wd: [647](#), [654](#), [655](#), [656](#), [729](#), [736](#), [737](#).
leaders: [1619](#).
Leaders not followed by...: [1254](#).
\leaders primitive: [1247](#).
least_cost: [1145](#), [1149](#), [1155](#).
least_page_cost: [1155](#), [1162](#), [1180](#), [1181](#).
left: [693](#).
\left primitive: [1364](#).

left_brace: [225](#), [311](#), [316](#), [320](#), [369](#), [379](#), [429](#), [499](#),
[951](#), [1239](#), [1326](#), [1402](#).
left_brace_limit: [311](#), [347](#), [348](#), [418](#), [420](#), [425](#), [502](#).
left_brace_token: [311](#), [429](#), [1303](#), [1402](#), [1615](#).
left_delimiter: [857](#), [870](#), [871](#), [911](#), [922](#), [1339](#),
[1357](#), [1358](#).
left_edge: [647](#), [655](#), [657](#), [660](#), [661](#), [665](#), [729](#), [730](#),
[738](#), [739](#), [742](#), [743](#), [746](#), [1636](#), [1640](#), [1641](#),
[1642](#), [1716](#), [1717](#), [1719](#).
left_hyphen_min: [254](#), [1267](#), [1376](#), [1621](#), [1622](#).
\lefthyphenmin primitive: [256](#).
left_hyphen_min_code: [254](#), [255](#), [256](#).
\leftmarginkern primitive: [494](#).
left_margin_kern_code: [494](#), [495](#), [497](#), [498](#).
left_noad: [230](#), [861](#), [864](#), [870](#), [872](#), [899](#), [901](#), [902](#),
[907](#), [934](#), [935](#), [936](#), [1361](#), [1364](#), [1365](#), [1367](#), [1676](#).
left_pw: [820](#), [821](#), [1003](#), [1061](#).
left_right: [226](#), [1222](#), [1364](#), [1365](#), [1366](#), [1694](#).
left_side: [173](#), [201](#), [498](#), [821](#), [1061](#).
left_skip: [242](#), [1001](#), [1054](#), [1061](#), [1737](#), [1840](#).
\leftskip primitive: [244](#).
left_skip_code: [242](#), [243](#), [244](#), [498](#), [1061](#), [1737](#), [1743](#).
left_to_right: [643](#), [1703](#), [1711](#), [1727](#), [1732](#).
len: [693](#).
length: [40](#), [46](#), [278](#), [281](#), [563](#), [629](#), [686](#), [693](#),
[702](#), [706](#), [712](#), [727](#), [749](#), [793](#), [799](#), [805](#), [1106](#),
[1116](#), [1456](#), [1627](#).
length of lines: [1021](#).
\leqno primitive: [1317](#).
let: [227](#), [1386](#), [1395](#), [1396](#), [1397](#).
\let primitive: [1395](#).
letter: [225](#), [250](#), [284](#), [311](#), [313](#), [316](#), [320](#), [369](#),
[376](#), [378](#), [1110](#), [1136](#), [1204](#), [1205](#), [1213](#), [1266](#),
[1300](#), [1327](#), [1330](#), [1336](#).
letter_space_font: [706](#).
letter_token: [311](#), [471](#).
letterspace_font: [227](#), [287](#), [288](#), [439](#), [604](#), [1386](#),
[1432](#).
\letterspacefont primitive: [287](#).
level: [436](#), [439](#), [441](#), [444](#), [454](#), [487](#), [1777](#).
level_boundary: [290](#), [292](#), [296](#), [304](#).
level_one: [239](#), [246](#), [250](#), [272](#), [277](#), [286](#), [294](#), [299](#),
[300](#), [301](#), [302](#), [303](#), [305](#), [954](#), [1480](#), [1513](#), [1613](#),
[1662](#), [1817](#), [1837](#), [1838](#).
level_zero: [239](#), [240](#), [294](#), [298](#), [302](#), [1833](#).
lf: [566](#), [586](#), [591](#), [592](#), [602](#), [603](#), [705](#), [706](#), [720](#).
lft_hit: [1081](#), [1082](#), [1083](#), [1085](#), [1086](#), [1208](#),
[1210](#), [1216](#).
lh: [128](#), [131](#), [132](#), [136](#), [231](#), [237](#), [274](#), [275](#), [566](#),
[567](#), [586](#), [591](#), [592](#), [594](#), [859](#), [1125](#), [1814](#).
Liang, Franklin Mark: [2](#), [1094](#).
libpdf_finish: [794](#).

- lig_char*: [161](#), [162](#), [211](#), [224](#), [705](#), [821](#), [823](#), [824](#),
[1015](#), [1016](#), [1040](#), [1044](#), [1045](#), [1073](#), [1078](#),
[1289](#), [1724](#), [1730](#).
lig_kern: [570](#), [571](#), [575](#).
lig_kern_base: [576](#), [578](#), [583](#), [592](#), [598](#), [600](#), [603](#),
[705](#), [706](#), [1498](#), [1499](#).
lig_kern_command: [567](#), [571](#).
lig_kern_restart: [583](#), [821](#), [915](#), [926](#), [1084](#), [1214](#).
lig_kern_restart_end: [583](#).
lig_kern_start: [583](#), [821](#), [915](#), [926](#), [1084](#), [1214](#).
lig_ptr: [161](#), [162](#), [193](#), [211](#), [220](#), [224](#), [821](#), [1071](#),
[1073](#), [1078](#), [1082](#), [1085](#), [1086](#), [1212](#), [1216](#), [1724](#).
lig_stack: [1082](#), [1083](#), [1085](#), [1086](#), [1207](#), [1209](#),
[1210](#), [1211](#), [1212](#), [1213](#), [1216](#).
lig_tag: [570](#), [595](#), [604](#), [705](#), [821](#), [915](#), [926](#), [1084](#),
[1214](#).
lig_trick: [180](#), [648](#), [731](#), [824](#).
ligature_node: [161](#), [162](#), [166](#), [193](#), [201](#), [220](#), [224](#),
[650](#), [705](#), [732](#), [821](#), [823](#), [926](#), [1015](#), [1016](#), [1040](#),
[1044](#), [1045](#), [1071](#), [1072](#), [1074](#), [1078](#), [1289](#),
[1297](#), [1323](#), [1724](#), [1730](#).
ligature_present: [1081](#), [1082](#), [1083](#), [1085](#), [1086](#),
[1208](#), [1210](#), [1212](#), [1216](#).
limit: [322](#), [324](#), [325](#), [329](#), [340](#), [350](#), [352](#), [353](#), [365](#),
[370](#), [372](#), [373](#), [374](#), [376](#), [377](#), [378](#), [382](#), [384](#), [385](#),
[509](#), [512](#), [563](#), [564](#), [1515](#), [1752](#), [1758](#).
Limit controls must follow...: [1335](#).
limit_field: [35](#), [87](#), [322](#), [324](#), [560](#).
limit_switch: [226](#), [1222](#), [1332](#), [1333](#), [1334](#).
limits: [856](#), [870](#), [907](#), [923](#), [1332](#), [1333](#).
\limits primitive: [1332](#).
line: [84](#), [234](#), [296](#), [321](#), [326](#), [335](#), [350](#), [351](#), [353](#),
[384](#), [450](#), [520](#), [521](#), [564](#), [837](#), [849](#), [1200](#), [1752](#).
line_break: [180](#), [988](#), [989](#), [997](#), [1002](#), [1013](#), [1022](#),
[1036](#), [1037](#), [1040](#), [1050](#), [1069](#), [1109](#), [1142](#),
[1145](#), [1157](#), [1272](#), [1321](#).
line_diff: [1046](#), [1049](#).
line_number: [993](#), [994](#), [1007](#), [1009](#), [1019](#), [1020](#),
[1024](#), [1038](#), [1046](#), [1048](#), [1049](#).
line_penalty: [254](#), [1033](#).
\linepenalty primitive: [256](#).
line_penalty_code: [254](#), [255](#), [256](#).
line_skip: [242](#), [265](#).
\lineskip primitive: [244](#).
line_skip_code: [167](#), [170](#), [242](#), [243](#), [244](#), [853](#).
line_skip_limit: [265](#), [853](#).
\lineskiplimit primitive: [266](#).
line_skip_limit_code: [265](#), [266](#).
line_stack: [326](#), [335](#), [350](#), [351](#).
line_width: [1004](#), [1024](#), [1025](#).
link: [136](#), [138](#), [139](#), [140](#), [141](#), [142](#), [143](#), [144](#), [148](#),
[151](#), [152](#), [153](#), [158](#), [159](#), [160](#), [161](#), [168](#), [182](#), [186](#),
[190](#), [192](#), [193](#), [194](#), [200](#), [220](#), [222](#), [230](#), [232](#), [236](#),
[241](#), [251](#), [314](#), [317](#), [321](#), [328](#), [341](#), [345](#), [348](#), [361](#),
[379](#), [380](#), [388](#), [393](#), [394](#), [397](#), [400](#), [415](#), [416](#), [417](#),
[420](#), [422](#), [423](#), [426](#), [433](#), [450](#), [478](#), [490](#), [492](#), [493](#),
[496](#), [497](#), [498](#), [504](#), [515](#), [521](#), [522](#), [523](#), [534](#), [632](#),
[634](#), [636](#), [638](#), [642](#), [648](#), [650](#), [658](#), [674](#), [686](#), [693](#),
[695](#), [700](#), [705](#), [727](#), [731](#), [732](#), [740](#), [766](#), [767](#), [771](#),
[772](#), [773](#), [775](#), [779](#), [781](#), [782](#), [783](#), [784](#), [786](#), [821](#),
[823](#), [824](#), [826](#), [829](#), [840](#), [843](#), [853](#), [855](#), [863](#), [879](#),
[885](#), [889](#), [892](#), [893](#), [894](#), [895](#), [901](#), [905](#), [906](#), [909](#),
[911](#), [912](#), [913](#), [921](#), [922](#), [925](#), [926](#), [927](#), [928](#),
[929](#), [930](#), [933](#), [934](#), [935](#), [940](#), [941](#), [944](#), [946](#),
[952](#), [953](#), [957](#), [958](#), [960](#), [964](#), [965](#), [967](#), [968](#),
[969](#), [970](#), [971](#), [972](#), [973](#), [975](#), [976](#), [977](#), [978](#),
[979](#), [980](#), [981](#), [982](#), [983](#), [986](#), [988](#), [990](#), [993](#),
[995](#), [996](#), [1003](#), [1004](#), [1011](#), [1014](#), [1017](#), [1018](#),
[1019](#), [1028](#), [1031](#), [1032](#), [1034](#), [1035](#), [1036](#), [1037](#),
[1038](#), [1039](#), [1040](#), [1041](#), [1043](#), [1047](#), [1048](#), [1049](#),
[1051](#), [1053](#), [1054](#), [1055](#), [1056](#), [1057](#), [1058](#), [1059](#),
[1060](#), [1061](#), [1065](#), [1069](#), [1071](#), [1072](#), [1073](#), [1074](#),
[1078](#), [1080](#), [1081](#), [1082](#), [1083](#), [1085](#), [1086](#), [1088](#),
[1089](#), [1090](#), [1091](#), [1092](#), [1093](#), [1107](#), [1113](#), [1135](#),
[1143](#), [1144](#), [1145](#), [1148](#), [1154](#), [1155](#), [1156](#), [1161](#),
[1163](#), [1166](#), [1169](#), [1173](#), [1174](#), [1175](#), [1176](#), [1180](#),
[1183](#), [1184](#), [1189](#), [1192](#), [1193](#), [1194](#), [1195](#), [1196](#),
[1197](#), [1198](#), [1201](#), [1210](#), [1211](#), [1212](#), [1216](#), [1217](#),
[1219](#), [1240](#), [1241](#), [1252](#), [1256](#), [1262](#), [1267](#), [1276](#),
[1277](#), [1286](#), [1295](#), [1296](#), [1297](#), [1299](#), [1301](#), [1322](#),
[1331](#), [1344](#), [1357](#), [1360](#), [1361](#), [1362](#), [1363](#), [1367](#),
[1370](#), [1372](#), [1375](#), [1380](#), [1381](#), [1382](#), [1394](#), [1402](#),
[1455](#), [1464](#), [1471](#), [1473](#), [1487](#), [1488](#), [1513](#), [1517](#),
[1519](#), [1527](#), [1543](#), [1563](#), [1571](#), [1575](#), [1612](#), [1615](#),
[1620](#), [1633](#), [1634](#), [1665](#), [1680](#), [1685](#), [1688](#), [1702](#),
[1704](#), [1706](#), [1709](#), [1718](#), [1719](#), [1721](#), [1722](#), [1724](#),
[1726](#), [1730](#), [1731](#), [1732](#), [1735](#), [1737](#), [1742](#), [1743](#),
[1750](#), [1751](#), [1753](#), [1754](#), [1765](#), [1769](#), [1773](#), [1774](#),
[1785](#), [1786](#), [1812](#), [1816](#), [1817](#), [1818](#), [1819](#), [1820](#),
[1821](#), [1822](#), [1825](#), [1834](#), [1838](#), [1860](#).
link_node: [730](#), [1629](#), [1632](#), [1633](#).
list_offset: [153](#), [647](#), [729](#), [821](#), [943](#), [1193](#).
list_ptr: [153](#), [154](#), [202](#), [220](#), [224](#), [498](#), [647](#), [651](#),
[657](#), [660](#), [729](#), [733](#), [738](#), [742](#), [821](#), [832](#), [837](#), [838](#),
[842](#), [847](#), [850](#), [883](#), [885](#), [889](#), [895](#), [913](#), [921](#), [925](#),
[981](#), [1003](#), [1152](#), [1154](#), [1196](#), [1263](#), [1276](#), [1286](#),
[1375](#), [1730](#), [1731](#), [1737](#), [1742](#), [1743](#).
list_state_record: [230](#), [231](#).
list_tag: [570](#), [595](#), [596](#), [604](#), [705](#), [882](#), [914](#), [923](#).
literal: [693](#), [726](#), [727](#).
literal_mode: [693](#), [727](#).
ll: [1128](#), [1131](#).
llink: [142](#), [144](#), [145](#), [147](#), [148](#), [149](#), [163](#), [167](#), [182](#),
[187](#), [946](#), [993](#), [995](#), [1488](#).

- ln*: [686](#).
- lo_mem_max*: [134](#), [138](#), [143](#), [144](#), [182](#), [183](#), [185](#), [187](#), [188](#), [189](#), [190](#), [196](#), [667](#), [1487](#), [1488](#), [1499](#), [1512](#).
- lo_mem_stat_max*: [180](#), [182](#), [453](#), [1397](#), [1413](#), [1488](#), [1829](#), [1831](#).
- load_expand_font*: [705](#).
- load_fmt_file*: [1479](#), [1515](#).
- loc*: [36](#), [37](#), [87](#), [322](#), [324](#), [325](#), [329](#), [334](#), [336](#), [340](#), [341](#), [345](#), [347](#), [348](#), [350](#), [352](#), [353](#), [365](#), [370](#), [372](#), [373](#), [374](#), [376](#), [378](#), [379](#), [380](#), [382](#), [384](#), [393](#), [394](#), [416](#), [509](#), [550](#), [563](#), [564](#), [1201](#), [1202](#), [1515](#), [1645](#), [1752](#), [1758](#).
- loc_field*: [35](#), [36](#), [322](#), [324](#), [1307](#).
- local_base*: [238](#), [242](#), [246](#), [248](#), [270](#).
- location*: [632](#), [634](#), [639](#), [640](#), [641](#), [642](#).
- log_file*: [54](#), [56](#), [75](#), [560](#), [1511](#).
- log_name*: [558](#), [560](#), [1511](#).
- log_only*: [54](#), [57](#), [58](#), [62](#), [75](#), [98](#), [382](#), [560](#), [1506](#), [1614](#).
- log_opened*: [92](#), [93](#), [553](#), [554](#), [560](#), [561](#), [1441](#), [1511](#), [1512](#).
- Logarithm...replaced by 0: [121](#).
- \long* primitive: [1384](#).
- long_call*: [228](#), [297](#), [388](#), [413](#), [415](#), [418](#), [425](#), [1471](#).
- long_char*: [710](#), [712](#), [717](#).
- long_help_seen*: [1457](#), [1458](#), [1459](#).
- long_outer_call*: [228](#), [297](#), [388](#), [413](#), [415](#), [1471](#).
- long_state*: [361](#), [413](#), [417](#), [418](#), [421](#), [422](#), [425](#).
- longinteger*: [65](#), [680](#), [685](#), [686](#), [694](#), [696](#), [702](#).
- loop**: [15](#), [16](#).
- Loose *\hbox*...: [834](#).
- Loose *\vbox*...: [848](#).
- loose_fit*: [991](#), [1008](#), [1026](#), [1844](#).
- looseness*: [254](#), [1022](#), [1047](#), [1049](#), [1246](#).
- \looseness* primitive: [256](#).
- looseness_code*: [254](#), [255](#), [256](#), [1246](#).
- \lower* primitive: [1247](#).
- \lowercase* primitive: [1462](#).
- lp*: [820](#), [1003](#).
- \lpcode* primitive: [1430](#).
- lp_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- lq*: [619](#), [655](#), [664](#).
- lr*: [619](#), [655](#), [664](#).
- LR_box*: [230](#), [231](#), [1321](#), [1382](#), [1739](#).
- LR_dir*: [1714](#), [1725](#), [1734](#), [1736](#).
- LR_problems*: [1702](#), [1703](#), [1708](#), [1709](#), [1710](#), [1714](#), [1715](#), [1720](#), [1725](#), [1727](#), [1732](#), [1736](#).
- LR_ptr*: [1051](#), [1702](#), [1703](#), [1704](#), [1705](#), [1706](#), [1708](#), [1709](#), [1714](#), [1715](#), [1720](#), [1725](#), [1727](#), [1732](#), [1734](#), [1736](#).
- LR_save*: [230](#), [231](#), [1051](#), [1272](#), [1728](#).
- lx*: [647](#), [654](#), [655](#), [656](#), [657](#), [663](#), [664](#), [665](#), [729](#), [736](#), [737](#), [738](#), [745](#), [746](#).
- m*: [47](#), [65](#), [176](#), [229](#), [236](#), [314](#), [337](#), [415](#), [439](#), [466](#), [508](#), [524](#), [604](#), [821](#), [842](#), [880](#), [890](#), [891](#), [1255](#), [1281](#), [1370](#), [1469](#), [1516](#), [1553](#), [1676](#), [1720](#), [1735](#), [1750](#).
- M_code*: [165](#).
- m_exp*: [110](#).
- m_log*: [110](#), [119](#), [121](#), [127](#).
- mac_param*: [225](#), [313](#), [316](#), [320](#), [369](#), [500](#), [503](#), [505](#), [957](#), [958](#), [1221](#).
- MacKay, Pierre: [1697](#).
- macro*: [329](#), [336](#), [341](#), [345](#), [346](#), [416](#).
- macro_call*: [313](#), [388](#), [406](#), [408](#), [413](#), [414](#), [415](#), [417](#).
- macro_def*: [499](#), [503](#).
- mag*: [254](#), [258](#), [310](#), [483](#), [612](#), [614](#), [615](#), [617](#), [645](#), [670](#), [690](#), [758](#).
- \mag* primitive: [256](#).
- mag_code*: [254](#), [255](#), [256](#), [310](#).
- mag_set*: [308](#), [309](#), [310](#).
- magic_offset*: [938](#), [939](#), [940](#).
- main_control*: [286](#), [1204](#), [1205](#), [1207](#), [1216](#), [1217](#), [1228](#), [1230](#), [1231](#), [1232](#), [1233](#), [1302](#), [1310](#), [1384](#), [1466](#), [1510](#), [1515](#), [1522](#), [1525](#).
- main_f*: [1207](#), [1209](#), [1210](#), [1211](#), [1212](#), [1213](#), [1214](#), [1216](#).
- main_i*: [1207](#), [1211](#), [1212](#), [1214](#), [1216](#).
- main_j*: [1207](#), [1214](#), [1216](#).
- main_k*: [1207](#), [1209](#), [1214](#), [1216](#), [1218](#).
- main_lig_loop*: [1205](#), [1209](#), [1212](#), [1213](#), [1214](#), [1216](#).
- main_loop*: [1205](#).
- main_loop_lookahead*: [1205](#), [1209](#), [1211](#), [1212](#), [1213](#).
- main_loop_move*: [1205](#), [1209](#), [1211](#), [1215](#), [1216](#).
- main_loop_move_lig*: [1205](#), [1209](#), [1211](#), [1212](#).
- main_loop_wrapup*: [1205](#), [1209](#), [1214](#), [1216](#).
- main_p*: [1207](#), [1210](#), [1212](#), [1216](#), [1217](#), [1218](#), [1219](#), [1220](#).
- main_s*: [1207](#), [1209](#).
- major_tail*: [1087](#), [1089](#), [1092](#), [1093](#).
- make_accent*: [1298](#), [1299](#).
- make_box*: [226](#), [1247](#), [1248](#), [1249](#), [1255](#), [1260](#).
- make_cstring*: [792](#).
- make_font_copy*: [706](#), [1432](#).
- make_frac*: [110](#), [112](#), [127](#).
- make_fraction*: [110](#), [907](#), [908](#), [917](#), [1796](#).
- make_left_right*: [935](#), [936](#).
- make_mark*: [1273](#), [1277](#).
- make_math_accent*: [907](#), [912](#).
- make_name_string*: [551](#).
- make_op*: [907](#), [923](#).
- make_ord*: [907](#), [926](#).

- make_over*: [907](#), [908](#).
- make_radical*: [907](#), [908](#), [911](#).
- make_scripts*: [928](#), [930](#).
- make_string*: [43](#), [48](#), [52](#), [279](#), [496](#), [543](#), [551](#), [686](#), [705](#), [706](#), [712](#), [718](#), [726](#), [727](#), [1114](#), [1433](#), [1455](#), [1506](#), [1511](#), [1750](#).
- make_under*: [907](#), [909](#).
- make_vcenter*: [907](#), [910](#).
- margin*: [1627](#).
- margin_char*: [173](#), [220](#), [224](#), [821](#), [823](#), [1286](#).
- margin_kern_node*: [173](#), [201](#), [220](#), [224](#), [498](#), [650](#), [732](#), [821](#), [823](#), [1286](#), [1323](#).
- margin_kern_node_size*: [173](#), [220](#), [224](#), [821](#), [1286](#).
- margin_kern_shrink*: [820](#), [1003](#), [1025](#).
- margin_kern_stretch*: [820](#), [1003](#), [1025](#).
- mark*: [226](#), [287](#), [288](#), [1273](#), [1806](#).
- \mark* primitive: [287](#).
- mark_class*: [159](#), [214](#), [1154](#), [1189](#), [1277](#), [1824](#), [1827](#).
- mark_class_node_size*: [1817](#), [1822](#).
- mark_node*: [159](#), [166](#), [193](#), [201](#), [220](#), [224](#), [817](#), [823](#), [904](#), [935](#), [1003](#), [1040](#), [1074](#), [1143](#), [1148](#), [1154](#), [1175](#), [1189](#), [1277](#).
- mark_ptr*: [159](#), [214](#), [220](#), [224](#), [1154](#), [1191](#), [1277](#), [1824](#), [1827](#).
- mark_text*: [329](#), [336](#), [345](#), [412](#).
- mark_val*: [1812](#), [1813](#), [1817](#), [1821](#), [1824](#), [1827](#).
- \marks* primitive: [1806](#).
- marks_code*: [318](#), [408](#), [411](#), [412](#), [1806](#).
- mastication*: [363](#).
- match*: [225](#), [311](#), [313](#), [314](#), [316](#), [417](#), [418](#).
- match_chr*: [314](#), [316](#), [415](#), [417](#), [426](#).
- match_token*: [311](#), [417](#), [418](#), [419](#), [420](#), [502](#).
- matching*: [327](#), [328](#), [361](#), [417](#).
- matchstrings*: [497](#).
- Math formula deleted...*: [1371](#).
- math_ac*: [1340](#), [1341](#).
- math_accent*: [226](#), [287](#), [288](#), [1222](#), [1340](#).
- \mathaccent* primitive: [287](#).
- \mathbin* primitive: [1332](#).
- math_char*: [855](#), [866](#), [894](#), [896](#), [898](#), [912](#), [915](#), [923](#), [926](#), [927](#), [928](#), [1327](#), [1331](#), [1341](#).
- \mathchar* primitive: [287](#).
- \mathchardef* primitive: [1398](#).
- math_char_def_code*: [1398](#), [1399](#), [1400](#).
- math_char_num*: [226](#), [287](#), [288](#), [1222](#), [1327](#), [1330](#).
- math_choice*: [226](#), [287](#), [288](#), [1222](#), [1347](#).
- \mathchoice* primitive: [287](#).
- math_choice_group*: [291](#), [1348](#), [1349](#), [1350](#), [1658](#), [1676](#).
- \mathclose* primitive: [1332](#).
- math_code*: [248](#), [250](#), [254](#), [440](#), [1327](#), [1330](#).
- \mathcode* primitive: [1406](#).
- math_code_base*: [248](#), [253](#), [440](#), [1406](#), [1407](#), [1408](#), [1409](#).
- math_comp*: [226](#), [1222](#), [1332](#), [1333](#), [1334](#).
- math_font_base*: [248](#), [250](#), [252](#), [1406](#), [1407](#).
- math_fraction*: [1356](#), [1357](#).
- math_given*: [226](#), [439](#), [1222](#), [1327](#), [1330](#), [1398](#), [1399](#), [1400](#).
- math_glue*: [890](#), [906](#), [940](#).
- math_group*: [291](#), [1312](#), [1326](#), [1329](#), [1362](#), [1658](#), [1676](#).
- \mathinner* primitive: [1332](#).
- math_kern*: [891](#), [904](#).
- math_left_group*: [230](#), [291](#), [1241](#), [1244](#), [1245](#), [1326](#), [1367](#), [1658](#), [1676](#).
- math_left_right*: [1366](#), [1367](#).
- math_limit_switch*: [1334](#), [1335](#).
- math_node*: [165](#), [166](#), [193](#), [201](#), [220](#), [224](#), [450](#), [650](#), [732](#), [823](#), [991](#), [1003](#), [1011](#), [1040](#), [1053](#), [1055](#), [1071](#), [1074](#), [1256](#), [1697](#), [1704](#), [1725](#), [1730](#), [1733](#), [1735](#).
- \mathop* primitive: [1332](#).
- \mathopen* primitive: [1332](#).
- \mathord* primitive: [1332](#).
- \mathpunct* primitive: [1332](#).
- math_quad*: [874](#), [877](#), [1375](#).
- math_radical*: [1338](#), [1339](#).
- \mathrel* primitive: [1332](#).
- math_shift*: [225](#), [311](#), [316](#), [320](#), [369](#), [1266](#), [1313](#), [1314](#), [1369](#), [1373](#), [1382](#).
- math_shift_group*: [291](#), [1241](#), [1244](#), [1245](#), [1306](#), [1315](#), [1316](#), [1318](#), [1321](#), [1368](#), [1369](#), [1370](#), [1376](#), [1658](#), [1676](#).
- math_shift_token*: [311](#), [1223](#), [1241](#).
- math_spacing*: [938](#), [939](#).
- math_style*: [226](#), [1222](#), [1345](#), [1346](#), [1347](#).
- math_surround*: [265](#), [1372](#).
- \mathsurround* primitive: [266](#).
- math_surround_code*: [265](#), [266](#).
- math_text_char*: [855](#), [926](#), [927](#), [928](#), [929](#).
- math_type*: [855](#), [857](#), [861](#), [866](#), [872](#), [894](#), [896](#), [897](#), [908](#), [909](#), [911](#), [912](#), [915](#), [916](#), [923](#), [925](#), [926](#), [927](#), [928](#), [929](#), [930](#), [1252](#), [1269](#), [1327](#), [1331](#), [1341](#), [1344](#), [1352](#), [1357](#), [1361](#), [1362](#), [1367](#).
- math_x.height*: [874](#), [911](#), [931](#), [932](#), [933](#).
- mathex*: [875](#).
- mathsy*: [874](#).
- mathsy_end*: [874](#).
- matrixrecalculate*: [1632](#).
- matrixtransformrect*: [1627](#).
- matrixused*: [1627](#), [1632](#), [1634](#).
- max*: [682](#), [727](#).
- max.answer*: [105](#), [1790](#), [1796](#).

max_buf_stack: [30](#), [31](#), [353](#), [400](#), [1512](#), [1753](#), [1765](#).
max_char_code: [225](#), [325](#), [363](#), [366](#), [1409](#).
max_command: [227](#), [228](#), [229](#), [237](#), [380](#), [388](#), [392](#),
[394](#), [406](#), [407](#), [504](#), [956](#), [1769](#).
max_d: [900](#), [901](#), [904](#), [934](#), [935](#), [936](#).
max_dead_cycles: [254](#), [258](#), [1187](#).
\maxdeadcycles primitive: [256](#).
max_dead_cycles_code: [254](#), [255](#), [256](#).
max_depth: [265](#), [1155](#), [1162](#).
\maxdepth primitive: [266](#).
max_depth_code: [265](#), [266](#).
max_dimen: [447](#), [486](#), [669](#), [842](#), [1185](#), [1192](#), [1321](#),
[1322](#), [1324](#), [1634](#), [1732](#), [1733](#), [1734](#), [1787](#),
[1789](#), [1795](#), [1843](#).
max_expand: [705](#).
max_group_code: [291](#).
max_h: [619](#), [620](#), [669](#), [670](#), [900](#), [901](#), [904](#), [934](#),
[935](#), [936](#).
max_halfword: [11](#), [14](#), [128](#), [129](#), [131](#), [142](#), [143](#), [144](#),
[149](#), [150](#), [311](#), [312](#), [450](#), [783](#), [786](#), [994](#), [1022](#),
[1024](#), [1157](#), [1166](#), [1171](#), [1192](#), [1282](#), [1425](#), [1499](#),
[1501](#), [1513](#), [1563](#), [1564](#), [1633](#), [1634](#).
max_hlist_stack: [173](#), [819](#), [1003](#).
max_in_open: [11](#), [14](#), [326](#), [350](#), [1657](#), [1770](#),
[1771](#), [1773](#).
max_in_stack: [323](#), [343](#), [353](#), [1512](#).
max_integer: [687](#), [689](#), [1553](#).
max_internal: [227](#), [439](#), [466](#), [474](#), [481](#), [487](#).
max_len: [693](#).
max_nest_stack: [231](#), [233](#), [234](#), [1512](#).
max_non_prefixed_command: [226](#), [1387](#), [1446](#).
max_param_stack: [330](#), [353](#), [416](#), [1512](#).
max_print_line: [11](#), [14](#), [54](#), [58](#), [72](#), [194](#), [563](#), [666](#),
[750](#), [1456](#), [1752](#).
max_push: [619](#), [620](#), [647](#), [657](#), [670](#).
max_quarterword: [11](#), [128](#), [129](#), [131](#), [173](#), [296](#),
[971](#), [972](#), [1119](#), [1296](#), [1501](#).
max_reg_help_line: [1808](#), [1809](#), [1810](#), [1811](#).
max_reg_num: [1808](#), [1809](#), [1810](#), [1811](#).
max_save_stack: [293](#), [294](#), [295](#), [1512](#).
max_selector: [54](#), [264](#), [333](#), [491](#), [496](#), [560](#), [666](#), [705](#),
[706](#), [712](#), [727](#), [1433](#), [1455](#), [1612](#), [1614](#), [1750](#).
max_shrink_ratio: [821](#), [997](#), [1001](#), [1025](#).
max_stretch_ratio: [821](#), [997](#), [1001](#), [1025](#).
max_strings: [11](#), [38](#), [43](#), [129](#), [543](#), [551](#), [1486](#), [1512](#).
max_v: [619](#), [620](#), [669](#), [670](#).
maxdimen: [110](#).
\meaning primitive: [494](#).
meaning_code: [494](#), [495](#), [497](#), [498](#).
med_mu_skip: [242](#).
\medmuskip primitive: [244](#).
med_mu_skip_code: [242](#), [243](#), [244](#), [940](#).

mediabox_given: [750](#), [769](#).
mem: [11](#), [12](#), [133](#), [134](#), [136](#), [142](#), [144](#), [149](#), [151](#),
[152](#), [153](#), [158](#), [160](#), [168](#), [169](#), [175](#), [177](#), [180](#), [181](#),
[182](#), [183](#), [185](#), [190](#), [200](#), [204](#), [221](#), [223](#), [224](#), [239](#),
[242](#), [297](#), [313](#), [413](#), [446](#), [515](#), [632](#), [695](#), [824](#), [854](#),
[855](#), [857](#), [860](#), [861](#), [894](#), [899](#), [916](#), [927](#), [943](#),
[944](#), [946](#), [971](#), [990](#), [992](#), [993](#), [996](#), [997](#), [1006](#),
[1017](#), [1018](#), [1021](#), [1022](#), [1024](#), [1034](#), [1035](#), [1064](#),
[1100](#), [1325](#), [1327](#), [1336](#), [1339](#), [1341](#), [1357](#), [1362](#),
[1423](#), [1424](#), [1487](#), [1488](#), [1517](#), [1671](#), [1724](#), [1730](#),
[1751](#), [1753](#), [1785](#), [1812](#), [1817](#), [1839](#).
mem_bot: [11](#), [12](#), [14](#), [129](#), [134](#), [143](#), [144](#), [180](#), [182](#),
[287](#), [437](#), [441](#), [453](#), [1397](#), [1402](#), [1403](#), [1413](#),
[1483](#), [1484](#), [1487](#), [1488](#), [1829](#), [1830](#), [1831](#).
mem_end: [134](#), [136](#), [138](#), [182](#), [183](#), [185](#), [186](#), [189](#),
[190](#), [192](#), [194](#), [200](#), [315](#), [674](#), [1487](#), [1488](#), [1512](#).
mem_max: [11](#), [12](#), [14](#), [128](#), [129](#), [134](#), [138](#), [142](#),
[143](#), [183](#), [184](#).
mem_min: [11](#), [12](#), [129](#), [134](#), [138](#), [143](#), [183](#), [184](#),
[185](#), [187](#), [188](#), [189](#), [190](#), [192](#), [196](#), [200](#), [674](#),
[1425](#), [1488](#), [1512](#).
mem_top: [11](#), [12](#), [14](#), [129](#), [134](#), [180](#), [182](#), [1425](#),
[1483](#), [1484](#), [1488](#).
Memory usage...: [667](#).
memory_word: [128](#), [131](#), [132](#), [134](#), [200](#), [230](#),
[236](#), [239](#), [271](#), [290](#), [293](#), [297](#), [574](#), [575](#), [710](#),
[974](#), [1481](#), [1813](#).
message: [226](#), [1452](#), [1453](#), [1454](#).
\message primitive: [1453](#).
METAFONT: [616](#).
microseconds: [680](#), [1515](#), [1553](#), [1582](#), [1584](#).
mid: [572](#).
mid_line: [87](#), [325](#), [350](#), [366](#), [369](#), [374](#), [375](#), [376](#).
middle: [1694](#).
\middle primitive: [1694](#).
middle_noad: [230](#), [861](#), [1367](#), [1368](#), [1694](#), [1695](#).
min: [682](#).
min_bp_val: [691](#), [692](#), [693](#), [792](#).
min_font_val: [691](#).
min_halfword: [11](#), [128](#), [129](#), [130](#), [131](#), [133](#), [248](#),
[1202](#), [1499](#), [1501](#), [1720](#), [1725](#), [1735](#), [1736](#).
min_internal: [226](#), [439](#), [466](#), [474](#), [481](#), [487](#).
min_quarterword: [12](#), [128](#), [129](#), [130](#), [131](#), [152](#), [154](#),
[158](#), [203](#), [239](#), [296](#), [575](#), [576](#), [580](#), [582](#), [583](#),
[592](#), [603](#), [821](#), [842](#), [859](#), [871](#), [881](#), [887](#), [888](#),
[970](#), [975](#), [977](#), [982](#), [1095](#), [1098](#), [1099](#), [1118](#),
[1119](#), [1120](#), [1121](#), [1133](#), [1138](#), [1139](#), [1140](#), [1169](#),
[1187](#), [1499](#), [1500](#), [1501](#).
minimal_demerits: [1007](#), [1008](#), [1010](#), [1019](#), [1029](#),
[1839](#).
minimum_demerits: [1007](#), [1008](#), [1009](#), [1010](#),
[1028](#), [1029](#).

- minor_tail*: [1087](#), [1090](#), [1091](#).
minus: [488](#).
Misplaced &: [1304](#).
Misplaced \cr: [1304](#).
Misplaced \noalign: [1305](#).
Misplaced \omit: [1305](#).
Misplaced \span: [1304](#).
Missing) inserted: [1781](#).
Missing = inserted: [529](#), [1766](#).
Missing # inserted...: [957](#).
Missing \$ inserted: [1223](#), [1241](#).
Missing \cr inserted: [1308](#).
Missing \endcsname...: [399](#).
Missing \endgroup inserted: [1241](#).
Missing \right. inserted: [1241](#).
Missing { inserted: [429](#), [501](#), [1303](#).
Missing } inserted: [1241](#), [1303](#).
Missing 'to' inserted: [1258](#).
Missing 'to'...: [1401](#).
Missing \$\$ inserted: [1383](#).
Missing character: [608](#).
Missing control...: [1391](#).
Missing delimiter...: [1337](#).
Missing font identifier: [604](#).
Missing number...: [441](#), [472](#).
mkern: [226](#), [1222](#), [1233](#), [1234](#), [1235](#).
\mkern primitive: [1234](#).
ml_field: [230](#), [231](#), [236](#).
mlist: [900](#), [934](#).
mlist_penalties: [893](#), [894](#), [900](#), [928](#), [1370](#), [1372](#), [1375](#).
mlist_to_hlist: [867](#), [893](#), [894](#), [899](#), [900](#), [908](#), [928](#), [934](#), [1370](#), [1372](#), [1375](#).
mm: [484](#).
mmode: [229](#), [230](#), [231](#), [236](#), [527](#), [892](#), [949](#), [950](#), [974](#), [981](#), [986](#), [1205](#), [1221](#), [1222](#), [1224](#), [1232](#), [1233](#), [1249](#), [1256](#), [1268](#), [1273](#), [1285](#), [1286](#), [1288](#), [1292](#), [1296](#), [1306](#), [1312](#), [1316](#), [1321](#), [1326](#), [1330](#), [1334](#), [1338](#), [1340](#), [1343](#), [1347](#), [1351](#), [1356](#), [1366](#), [1369](#), [1370](#), [1676](#), [1739](#).
moddate_given: [805](#).
mode: [229](#), [230](#), [231](#), [233](#), [234](#), [321](#), [444](#), [448](#), [450](#), [527](#), [892](#), [949](#), [950](#), [959](#), [960](#), [961](#), [970](#), [973](#), [978](#), [981](#), [982](#), [983](#), [986](#), [1200](#), [1204](#), [1205](#), [1209](#), [1210](#), [1225](#), [1227](#), [1232](#), [1252](#), [1254](#), [1256](#), [1259](#), [1262](#), [1267](#), [1269](#), [1270](#), [1271](#), [1272](#), [1275](#), [1279](#), [1281](#), [1286](#), [1293](#), [1295](#), [1296](#), [1312](#), [1314](#), [1321](#), [1343](#), [1370](#), [1372](#), [1376](#), [1419](#), [1558](#), [1559](#), [1614](#), [1615](#), [1622](#), [1739](#).
mode_field: [230](#), [231](#), [236](#), [448](#), [974](#), [981](#), [1420](#), [1676](#), [1678](#).
mode_line: [230](#), [231](#), [233](#), [234](#), [326](#), [978](#), [989](#), [1200](#).
month: [254](#), [259](#), [645](#), [792](#), [1506](#).
\month primitive: [256](#).
month_code: [254](#), [255](#), [256](#).
months: [560](#), [562](#).
more_name: [538](#), [542](#), [552](#), [557](#).
\moveleft primitive: [1247](#).
move_past: [647](#), [650](#), [653](#), [657](#), [659](#), [662](#), [729](#), [732](#), [735](#), [738](#), [741](#), [744](#).
\moveright primitive: [1247](#).
movement: [634](#), [636](#), [643](#).
movement_node_size: [632](#), [634](#), [642](#).
msg: [712](#).
mskip: [226](#), [1222](#), [1233](#), [1234](#), [1235](#).
\mskip primitive: [1234](#).
mskip_code: [1234](#), [1236](#).
mstate: [634](#), [638](#), [639](#).
mtype: [4](#).
mu: [473](#), [474](#), [475](#), [479](#), [481](#), [487](#), [488](#).
mu: [482](#).
mu_error: [434](#), [455](#), [475](#), [481](#), [487](#), [1777](#).
\muexpr primitive: [1775](#).
mu_glue: [167](#), [173](#), [209](#), [450](#), [891](#), [906](#), [1234](#), [1236](#), [1237](#).
mu_mult: [890](#), [891](#).
mu_skip: [242](#), [453](#).
\muskip primitive: [437](#).
mu_skip_base: [242](#), [245](#), [247](#), [1400](#), [1413](#).
\muskipdef primitive: [1398](#).
mu_skip_def_code: [1398](#), [1399](#), [1400](#).
\mutogluue primitive: [1802](#).
mu_to_glue_code: [1802](#), [1803](#), [1804](#).
mu_val: [436](#), [437](#), [439](#), [450](#), [453](#), [455](#), [456](#), [475](#), [477](#), [481](#), [487](#), [491](#), [1236](#), [1400](#), [1404](#), [1412](#), [1413](#), [1775](#), [1776](#), [1777](#), [1784](#), [1812](#), [1817](#), [1820](#).
mu_val_limit: [1812](#), [1818](#), [1835](#).
mult_and_add: [105](#).
mult_integers: [105](#), [1416](#), [1792](#).
multiply: [227](#), [287](#), [288](#), [1386](#), [1411](#), [1412](#), [1416](#).
\multiply primitive: [287](#).
Must increase the x: [1479](#).
must_end_string: [693](#).
must_insert_space: [693](#).
n: [47](#), [65](#), [66](#), [67](#), [69](#), [91](#), [94](#), [105](#), [106](#), [107](#), [112](#), [114](#), [170](#), [172](#), [192](#), [200](#), [243](#), [255](#), [265](#), [270](#), [314](#), [320](#), [321](#), [337](#), [415](#), [508](#), [524](#), [544](#), [545](#), [549](#), [605](#), [674](#), [689](#), [880](#), [890](#), [891](#), [965](#), [974](#), [1081](#), [1109](#), [1119](#), [1152](#), [1167](#), [1168](#), [1169](#), [1187](#), [1255](#), [1295](#), [1314](#), [1387](#), [1451](#), [1469](#), [1516](#), [1720](#), [1735](#), [1779](#), [1794](#), [1796](#), [1816](#), [1819](#).
name: [322](#), [324](#), [325](#), [326](#), [329](#), [333](#), [335](#), [336](#), [345](#), [350](#), [351](#), [353](#), [359](#), [382](#), [384](#), [416](#), [509](#), [563](#), [1752](#).
name_field: [84](#), [85](#), [322](#), [324](#), [1771](#), [1772](#).

- name_in_progress*: [404](#), [552](#), [553](#), [554](#), [1434](#).
- name_length*: [26](#), [51](#), [545](#), [549](#), [551](#).
- name_of_file*: [26](#), [27](#), [51](#), [545](#), [549](#), [551](#), [556](#).
- name_tree_kids_max*: [695](#), [803](#).
- named*: [1550](#).
- names_head*: [802](#), [803](#), [1511](#).
- names_tail*: [802](#), [1511](#).
- names_tree*: [802](#), [804](#), [1511](#).
- natural*: [814](#), [879](#), [889](#), [894](#), [901](#), [909](#), [911](#), [912](#),
[922](#), [928](#), [930](#), [933](#), [970](#), [973](#), [980](#), [1152](#), [1196](#),
[1276](#), [1301](#), [1370](#), [1375](#), [1380](#), [1743](#).
- nc*: [484](#).
- nd*: [484](#).
- nd*: [566](#), [567](#), [586](#), [591](#), [592](#), [595](#).
- ne*: [566](#), [567](#), [586](#), [591](#), [592](#), [595](#).
- neg*: [705](#).
- negate*: [16](#), [65](#), [103](#), [105](#), [106](#), [107](#), [112](#), [115](#), [123](#),
[456](#), [457](#), [466](#), [474](#), [487](#), [686](#), [689](#), [949](#), [1583](#),
[1766](#), [1777](#), [1790](#), [1794](#), [1796](#).
- negative*: [106](#), [112](#), [114](#), [115](#), [439](#), [456](#), [466](#), [467](#),
[474](#), [487](#), [1777](#), [1790](#), [1794](#), [1796](#).
- nest*: [230](#), [231](#), [234](#), [235](#), [236](#), [237](#), [439](#), [448](#), [949](#),
[974](#), [981](#), [1170](#), [1420](#), [1676](#), [1678](#).
- nest_ptr*: [231](#), [233](#), [234](#), [235](#), [236](#), [448](#), [949](#), [974](#),
[981](#), [1170](#), [1192](#), [1198](#), [1267](#), [1276](#), [1321](#),
[1376](#), [1420](#), [1676](#).
- nest_size*: [11](#), [231](#), [234](#), [236](#), [439](#), [1420](#), [1512](#), [1676](#).
- nesting_level*: [730](#), [1629](#), [1632](#).
- new_annot_whatsit*: [1554](#), [1556](#), [1558](#), [1565](#), [1566](#).
- new_character*: [609](#), [929](#), [1090](#), [1293](#), [1299](#), [1300](#).
- new_choice*: [863](#), [1348](#).
- new_delta_from_break_width*: [1018](#).
- new_delta_to_break_width*: [1017](#).
- new_disc*: [163](#), [1210](#), [1293](#).
- new_dummy_font*: [673](#).
- new_edge*: [1716](#), [1719](#), [1735](#).
- new_font*: [706](#), [1432](#), [1433](#).
- new_font_type*: [703](#), [705](#), [720](#), [726](#).
- new_glue*: [171](#), [172](#), [889](#), [940](#), [960](#), [967](#), [969](#), [983](#),
[1217](#), [1219](#), [1230](#), [1236](#), [1347](#).
- new_graf*: [1266](#), [1267](#).
- new_hlist*: [899](#), [901](#), [917](#), [922](#), [923](#), [924](#), [928](#),
[930](#), [936](#), [941](#).
- new_hyph_exceptions*: [1109](#), [1428](#).
- new_index*: [1812](#), [1813](#), [1816](#).
- new_interaction*: [1440](#), [1441](#), [1692](#), [1693](#).
- new_kern*: [174](#), [705](#), [879](#), [889](#), [909](#), [912](#), [913](#), [921](#),
[925](#), [927](#), [929](#), [933](#), [1085](#), [1216](#), [1237](#), [1288](#),
[1289](#), [1301](#), [1380](#), [1718](#), [1737](#), [1743](#).
- new_letterspaced_font*: [706](#), [1432](#).
- new_lig_item*: [162](#), [1086](#), [1216](#).
- new_ligature*: [162](#), [1085](#), [1210](#).
- new_line*: [325](#), [353](#), [365](#), [366](#), [367](#), [369](#), [509](#), [563](#).
- new_line_char*: [59](#), [254](#), [262](#), [1511](#), [1513](#), [1751](#).
- \newlinechar* primitive: [256](#).
- new_line_char_code*: [254](#), [255](#), [256](#).
- new_margin_kern*: [821](#), [1055](#), [1061](#).
- new_math*: [165](#), [1372](#), [1700](#), [1704](#), [1706](#), [1709](#),
[1720](#), [1731](#), [1743](#).
- new_noad*: [860](#), [894](#), [916](#), [927](#), [1252](#), [1269](#), [1326](#),
[1331](#), [1334](#), [1344](#), [1353](#), [1367](#).
- new_null_box*: [154](#), [880](#), [883](#), [887](#), [894](#), [921](#), [924](#),
[953](#), [967](#), [983](#), [1193](#), [1230](#), [1267](#), [1269](#), [1737](#).
- new_param_glue*: [170](#), [172](#), [853](#), [952](#), [990](#), [1060](#),
[1061](#), [1217](#), [1219](#), [1267](#), [1379](#), [1381](#), [1382](#), [1737](#).
- new_patterns*: [1135](#), [1428](#).
- new_penalty*: [176](#), [941](#), [990](#), [1065](#), [1230](#), [1279](#),
[1379](#), [1381](#), [1382](#).
- new_randoms*: [110](#), [124](#), [125](#).
- new_rule*: [157](#), [489](#), [840](#), [878](#), [1550](#).
- new_save_level*: [296](#), [815](#), [948](#), [959](#), [965](#), [1200](#),
[1239](#), [1275](#), [1293](#), [1295](#), [1312](#).
- new_skip_param*: [172](#), [853](#), [1144](#), [1176](#), [1743](#).
- new_snap_node*: [1571](#), [1572](#).
- new_spec*: [169](#), [172](#), [456](#), [488](#), [705](#), [1000](#), [1151](#),
[1179](#), [1218](#), [1219](#), [1415](#), [1416](#), [1777](#), [1787](#),
[1788](#), [1850](#).
- new_string*: [54](#), [57](#), [58](#), [491](#), [496](#), [645](#), [686](#), [705](#), [706](#),
[712](#), [727](#), [1433](#), [1455](#), [1506](#), [1612](#), [1685](#), [1750](#).
- new_style*: [862](#), [1347](#).
- new_trie_op*: [1118](#), [1119](#), [1120](#), [1140](#).
- new_vf_packet*: [706](#), [716](#).
- new_whatsit*: [1527](#), [1528](#), [1532](#), [1536](#), [1537](#), [1538](#),
[1539](#), [1540](#), [1544](#), [1547](#), [1552](#), [1554](#), [1559](#),
[1563](#), [1567](#), [1570](#), [1573](#), [1574](#), [1592](#), [1593](#), [1594](#),
[1595](#), [1596](#), [1621](#), [1622](#).
- new_write_whatsit*: [1528](#), [1529](#), [1530](#), [1531](#).
- newcolorstack*: [497](#).
- next*: [274](#), [276](#), [278](#), [279](#).
- next_break*: [1051](#), [1052](#).
- next_char*: [571](#), [821](#), [915](#), [927](#), [1084](#), [1214](#).
- next_char_p*: [997](#).
- next_p*: [647](#), [650](#), [654](#), [657](#), [658](#), [659](#), [661](#), [663](#), [729](#),
[732](#), [736](#), [738](#), [740](#), [741](#), [743](#), [745](#), [1720](#), [1722](#).
- next_pos*: [1634](#).
- next_random*: [124](#), [126](#), [127](#).
- nh*: [566](#), [567](#), [586](#), [591](#), [592](#), [595](#).
- ni*: [566](#), [567](#), [586](#), [591](#), [592](#), [595](#), [705](#).
- nil*: [16](#).
- nk*: [566](#), [567](#), [586](#), [591](#), [592](#), [600](#), [705](#).
- nl*: [59](#), [566](#), [567](#), [571](#), [586](#), [591](#), [592](#), [595](#), [600](#),
[603](#), [1750](#), [1751](#).
- nn*: [333](#), [334](#).
- No pages of output: [670](#), [794](#).

- `no_align`: [226](#), [287](#), [288](#), [959](#), [1302](#).
`\noalign` primitive: [287](#).
`no_align_error`: [1302](#), [1305](#).
`no_align_group`: [291](#), [942](#), [959](#), [1309](#), [1658](#), [1676](#).
`no_boundary`: [226](#), [287](#), [288](#), [1205](#), [1213](#), [1221](#), [1266](#).
`\noboundary` primitive: [287](#).
`no_break_yet`: [1003](#), [1010](#), [1011](#).
`no_expand`: [228](#), [287](#), [288](#), [388](#), [391](#).
`\noexpand` primitive: [287](#).
`no_expand_flag`: [380](#), [504](#), [532](#).
`\noindent` primitive: [1264](#).
`no_lig_code`: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
`\pdfnoligatures` primitive: [1430](#).
`no_limits`: [856](#), [1332](#), [1333](#).
`\nolimits` primitive: [1332](#).
`no_new_control_sequence`: [274](#), [276](#), [278](#), [281](#), [286](#), [387](#), [400](#), [1514](#), [1645](#), [1765](#).
`no_print`: [54](#), [57](#), [58](#), [75](#), [98](#).
`no_shrink_error_yet`: [999](#), [1000](#), [1001](#).
`no_tag`: [570](#), [595](#).
`no_zip`: [680](#), [681](#), [685](#).
`noad_size`: [855](#), [860](#), [872](#), [927](#), [935](#), [1362](#), [1363](#).
`node_list_display`: [198](#), [202](#), [206](#), [208](#), [213](#), [215](#).
`node_r_stays_active`: [1004](#), [1025](#), [1028](#).
`node_size`: [142](#), [144](#), [145](#), [146](#), [148](#), [182](#), [187](#), [1487](#), [1488](#).
`nom`: [586](#), [587](#), [589](#), [603](#).
`non_address`: [575](#), [578](#), [603](#), [1084](#), [1091](#), [1209](#).
`non_char`: [575](#), [578](#), [603](#), [705](#), [1072](#), [1073](#), [1076](#), [1083](#), [1084](#), [1085](#), [1086](#), [1090](#), [1091](#), [1092](#), [1207](#), [1209](#), [1210](#), [1213](#), [1214](#), [1216](#), [1499](#).
`non_discardable`: [166](#), [1003](#), [1053](#).
`non_existent_path`: [705](#), [706](#).
`non_math`: [1222](#), [1239](#), [1320](#).
`non_script`: [226](#), [287](#), [288](#), [1222](#), [1347](#).
`\nonscript` primitive: [287](#), [906](#).
`none_seen`: [638](#), [639](#).
`NONEXISTENT`: [284](#).
`Nonletter`: [1137](#).
`nonnegative_integer`: [69](#), [101](#), [107](#), [689](#).
`nonstop_mode`: [73](#), [86](#), [382](#), [385](#), [510](#), [1438](#), [1439](#).
`\nonstopmode` primitive: [1438](#).
`nop`: [610](#), [612](#), [613](#), [615](#), [617](#), [717](#), [719](#).
`norm_min`: [1267](#), [1376](#), [1621](#), [1622](#).
`norm_rand`: [110](#), [127](#), [498](#).
`normal`: [153](#), [154](#), [167](#), [168](#), [171](#), [173](#), [174](#), [182](#), [195](#), [204](#), [207](#), [209](#), [327](#), [353](#), [358](#), [393](#), [394](#), [465](#), [474](#), [497](#), [499](#), [506](#), [508](#), [511](#), [515](#), [516](#), [527](#), [533](#), [647](#), [653](#), [657](#), [662](#), [729](#), [735](#), [738](#), [744](#), [822](#), [823](#), [831](#), [832](#), [833](#), [834](#), [838](#), [839](#), [840](#), [841](#), [846](#), [847](#), [848](#), [850](#), [851](#), [852](#), [856](#), [860](#), [870](#), [890](#), [906](#), [923](#), [951](#), [975](#), [984](#), [985](#), [999](#), [1000](#), [1003](#), [1015](#), [1016](#), [1040](#), [1044](#), [1045](#), [1071](#), [1072](#), [1074](#), [1151](#), [1163](#), [1179](#), [1184](#), [1221](#), [1332](#), [1339](#), [1341](#), [1357](#), [1377](#), [1395](#), [1396](#), [1397](#), [1415](#), [1469](#), [1634](#), [1635](#), [1680](#), [1720](#), [1763](#), [1788](#), [1791](#), [1840](#).
`\pdfnormaldeviate` primitive: [494](#).
`normal_deviate_code`: [494](#), [495](#), [497](#), [498](#).
`normal_paragraph`: [948](#), [959](#), [961](#), [1200](#), [1246](#), [1259](#), [1270](#), [1272](#), [1275](#), [1343](#).
`normalize_glue`: [1788](#), [1791](#).
`normalize_selector`: [78](#), [92](#), [93](#), [94](#), [95](#), [686](#), [1037](#).
`Not a letter`: [1112](#).
`not_found`: [15](#), [45](#), [46](#), [474](#), [481](#), [586](#), [596](#), [634](#), [638](#), [639](#), [686](#), [1003](#), [1070](#), [1105](#), [1106](#), [1109](#), [1116](#), [1128](#), [1130](#), [1145](#), [1147](#), [1148](#), [1314](#), [1322](#), [1609](#), [1730](#), [1816](#), [1843](#).
`not_found1`: [15](#), [1109](#), [1816](#).
`not_found2`: [15](#), [1816](#).
`not_found3`: [15](#), [1816](#).
`not_found4`: [15](#), [1816](#).
`notexpanded:`: [277](#).
`np`: [566](#), [567](#), [586](#), [591](#), [592](#), [602](#), [603](#).
`nucleus`: [855](#), [856](#), [857](#), [860](#), [861](#), [864](#), [870](#), [872](#), [894](#), [899](#), [908](#), [909](#), [910](#), [911](#), [912](#), [915](#), [916](#), [923](#), [924](#), [926](#), [927](#), [928](#), [929](#), [1252](#), [1269](#), [1326](#), [1327](#), [1331](#), [1334](#), [1339](#), [1341](#), [1344](#), [1362](#), [1367](#).
`null`: [133](#), [134](#), [136](#), [138](#), [140](#), [141](#), [143](#), [144](#), [153](#), [154](#), [162](#), [163](#), [167](#), [168](#), [169](#), [170](#), [171](#), [172](#), [182](#), [186](#), [187](#), [193](#), [194](#), [200](#), [218](#), [219](#), [220](#), [222](#), [228](#), [230](#), [233](#), [234](#), [236](#), [237](#), [240](#), [241](#), [250](#), [251](#), [297](#), [314](#), [317](#), [321](#), [328](#), [329](#), [334](#), [336](#), [347](#), [353](#), [379](#), [380](#), [384](#), [397](#), [400](#), [408](#), [409](#), [412](#), [416](#), [417](#), [418](#), [423](#), [426](#), [433](#), [436](#), [441](#), [446](#), [449](#), [453](#), [478](#), [490](#), [492](#), [497](#), [498](#), [499](#), [504](#), [508](#), [515](#), [516](#), [523](#), [531](#), [534](#), [575](#), [578](#), [603](#), [605](#), [609](#), [633](#), [638](#), [642](#), [647](#), [651](#), [657](#), [660](#), [673](#), [674](#), [686](#), [693](#), [700](#), [705](#), [727](#), [729](#), [733](#), [738](#), [739](#), [742](#), [753](#), [754](#), [756](#), [763](#), [764](#), [766](#), [767](#), [769](#), [771](#), [772](#), [773](#), [775](#), [778](#), [779](#), [781](#), [782](#), [783](#), [784](#), [786](#), [792](#), [795](#), [801](#), [802](#), [804](#), [805](#), [812](#), [813](#), [818](#), [820](#), [821](#), [823](#), [828](#), [829](#), [832](#), [838](#), [840](#), [842](#), [847](#), [850](#), [855](#), [859](#), [863](#), [866](#), [889](#), [892](#), [893](#), [894](#), [895](#), [900](#), [905](#), [906](#), [926](#), [928](#), [929](#), [930](#), [934](#), [935](#), [940](#), [941](#), [945](#), [948](#), [950](#), [951](#), [957](#), [958](#), [963](#), [964](#), [965](#), [966](#), [968](#), [970](#), [971](#), [973](#), [975](#), [978](#), [979](#), [980](#), [981](#), [986](#), [995](#), [1001](#), [1003](#), [1011](#), [1014](#), [1020](#), [1021](#), [1022](#), [1024](#), [1025](#), [1026](#), [1030](#), [1031](#), [1032](#), [1033](#), [1037](#), [1038](#), [1039](#), [1041](#), [1043](#), [1046](#), [1051](#), [1052](#), [1053](#), [1055](#), [1056](#), [1057](#), [1058](#), [1059](#), [1061](#), [1063](#), [1064](#), [1065](#), [1069](#), [1071](#), [1073](#), [1078](#), [1081](#), [1082](#), [1083](#), [1085](#), [1086](#), [1088](#), [1089](#), [1090](#), [1091](#), [1092](#), [1093](#), [1103](#), [1107](#), [1110](#), [1143](#), [1144](#), [1145](#), [1147](#), [1148](#), [1152](#), [1153](#),

- 1154, 1156, 1166, 1167, 1168, 1169, 1173, 1174, 1175, 1184, 1185, 1186, 1187, 1189, 1190, 1191, 1192, 1193, 1195, 1196, 1197, 1198, 1201, 1202, 1203, 1205, 1207, 1209, 1210, 1211, 1212, 1213, 1215, 1216, 1218, 1219, 1246, 1250, 1251, 1252, 1255, 1256, 1259, 1263, 1267, 1272, 1286, 1297, 1299, 1300, 1307, 1312, 1315, 1321, 1322, 1325, 1343, 1350, 1352, 1357, 1360, 1361, 1362, 1370, 1372, 1375, 1378, 1381, 1382, 1402, 1403, 1423, 1424, 1459, 1464, 1472, 1487, 1488, 1513, 1517, 1531, 1532, 1534, 1542, 1543, 1546, 1549, 1550, 1553, 1554, 1563, 1571, 1575, 1600, 1601, 1602, 1612, 1613, 1620, 1626, 1627, 1633, 1634, 1665, 1671, 1680, 1688, 1703, 1704, 1705, 1706, 1709, 1718, 1720, 1722, 1727, 1728, 1730, 1731, 1732, 1735, 1742, 1743, 1748, 1753, 1754, 1755, 1765, 1779, 1780, 1781, 1806, 1812, 1813, 1814, 1815, 1816, 1817, 1818, 1820, 1821, 1822, 1823, 1824, 1825, 1826, 1827, 1828, 1829, 1833, 1834, 1835, 1838, 1846, 1849, 1857, 1860, 1863.
- null delimiter*: 258, 1241.
- null character*: 581, 582, 896, 897.
- null code*: 22, 250.
- null cs*: 240, 284, 285, 376, 400, 673, 693, 705, 706, 712, 1433, 1765.
- null delimiter*: 858, 859, 1357.
- null delimiter space*: 265, 880.
- \nulldelimiterspace* primitive: 266.
- null delimiter space code*: 265, 266.
- null flag*: 156, 157, 489, 825, 953, 967, 975, 1550.
- null font*: 192, 250, 497, 578, 579, 586, 604, 645, 673, 674, 693, 697, 705, 706, 712, 720, 821, 837, 880, 881, 896, 1038, 1433, 1496, 1497, 1517, 1585, 1587, 1591.
- \nullfont* primitive: 579.
- null list*: 14, 180, 406, 954.
- num*: 476, 484, 612, 614, 617.
- num error*: 1787, 1790, 1794, 1796.
- \numexpr* primitive: 1775.
- num style*: 876, 918.
- Number too big*: 471.
- \number* primitive: 494.
- number code*: 494, 495, 496, 497, 498.
- numerator*: 857, 864, 871, 872, 918, 1357, 1361.
- num1*: 874, 918.
- num2*: 874, 918.
- num3*: 874, 918.
- nw*: 566, 567, 586, 591, 592, 595, 705, 706.
- nx plus y*: 105, 481, 890, 1416, 1792.
- o*: 286, 634, 821, 842, 965, 974, 1779.
- obj annot ptr*: 695, 781, 782, 783, 1556, 1558, 1627, 1632, 1633.
- obj aux*: 695, 698, 752, 797, 803.
- obj bead attr*: 695, 1597, 1634.
- obj bead data*: 695, 786, 1634.
- obj bead next*: 695, 1597, 1634.
- obj bead page*: 695, 1597, 1634.
- obj bead prev*: 695, 1597, 1634.
- obj bead ptr*: 695, 1634.
- obj bead rect*: 695, 786, 1597.
- obj data ptr*: 695, 1542, 1546, 1550, 1620.
- obj dest ptr*: 695, 784, 795, 1553, 1563, 1634.
- obj entry*: 694, 695, 696, 698.
- obj info*: 498, 693, 695, 698, 767, 794, 795, 797, 799, 800, 801, 802, 803, 1597, 1634.
- obj link*: 693, 695, 698, 789, 790, 796, 797, 798, 799, 800, 801, 802, 803, 810, 811, 812, 1543.
- obj obj data*: 695, 772, 1542, 1600.
- obj obj is file*: 695, 772, 1542, 1600.
- obj obj is stream*: 695, 772, 1542, 1600.
- obj obj stream attr*: 695, 772, 1542, 1600.
- obj offset*: 695, 698, 811, 812, 813.
- obj os idx*: 695, 698, 812.
- obj outline action objnum*: 695, 789, 1561.
- obj outline attr*: 695, 789, 1561.
- obj outline count*: 695, 788, 789, 1561, 1634.
- obj outline first*: 695, 789, 1561, 1634.
- obj outline last*: 695, 789, 1561, 1634.
- obj outline next*: 695, 788, 789, 1561, 1634.
- obj outline parent*: 695, 788, 789, 1561, 1634.
- obj outline prev*: 695, 789, 1560, 1561.
- obj outline ptr*: 695, 1561.
- obj outline title*: 695, 789, 1561.
- obj ptr*: 693, 696, 697, 698, 752, 770, 786, 788, 790, 802, 804, 811, 812, 1502, 1503, 1511, 1542, 1546, 1550, 1553, 1556, 1561, 1577, 1597, 1633.
- obj tab*: 694, 695, 696, 697, 698, 802, 1502, 1503.
- obj tab size*: 694, 696, 697, 698, 1502, 1503, 1511.
- obj thread first*: 695, 1597, 1634.
- obj type dest*: 695, 698, 796, 1553, 1563, 1627, 1634.
- obj type font*: 693, 695, 799.
- obj type obj*: 695, 1502, 1503, 1542, 1544.
- obj type others*: 695, 698, 752, 786, 788, 790, 802, 804, 805, 812, 1561, 1577, 1597, 1633.
- obj type outline*: 695, 789, 1561.
- obj type page*: 498, 695, 698, 752, 795, 797, 798, 800, 1597, 1627.
- obj type pages*: 695, 770, 798, 800, 801.
- obj type thread*: 695, 790, 1627, 1634.
- obj type xform*: 497, 695, 1502, 1503, 1546, 1547.
- obj type ximage*: 497, 695, 1502, 1503, 1550, 1552.
- obj xform attr*: 695, 756, 1546.
- obj xform box*: 695, 775, 1546, 1620.

- obj_xform_depth*: [695](#), [1546](#), [1547](#), [1600](#), [1634](#).
- obj_xform_height*: [695](#), [1546](#), [1547](#), [1600](#).
- obj_xform_resources*: [695](#), [763](#), [1546](#).
- obj_xform_width*: [695](#), [1546](#), [1547](#), [1600](#).
- obj_ximage_attr*: [695](#), [778](#), [1550](#).
- obj_ximage_data*: [497](#), [695](#), [767](#), [778](#), [1550](#), [1634](#).
- obj_ximage_depth*: [695](#), [1550](#), [1552](#), [1600](#).
- obj_ximage_height*: [695](#), [1550](#), [1552](#), [1600](#).
- obj_ximage_width*: [695](#), [1550](#), [1552](#), [1600](#).
- objname*: [698](#), [793](#), [803](#), [1624](#).
- objnum*: [698](#), [803](#), [1624](#).
- octal_token*: [464](#), [470](#).
- odd*: [62](#), [100](#), [116](#), [165](#), [211](#), [530](#), [604](#), [702](#), [932](#),
[1040](#), [1073](#), [1077](#), [1083](#), [1084](#), [1088](#), [1089](#), [1387](#),
[1394](#), [1424](#), [1471](#), [1685](#), [1797](#), [1816](#), [1821](#).
- off_save*: [1239](#), [1240](#), [1270](#), [1271](#), [1306](#), [1307](#),
[1316](#), [1368](#), [1369](#).
- OK*: [1474](#).
- OK_so_far*: [466](#), [471](#).
- OK_to_interrupt*: [88](#), [96](#), [97](#), [98](#), [349](#), [1206](#).
- old_l*: [1003](#), [1009](#), [1024](#).
- old_mode*: [1614](#), [1615](#).
- old_rover*: [149](#).
- old_setting*: [263](#), [264](#), [333](#), [334](#), [491](#), [496](#), [560](#),
[608](#), [645](#), [666](#), [686](#), [705](#), [706](#), [712](#), [727](#), [1433](#),
[1455](#), [1612](#), [1614](#), [1685](#), [1750](#).
- omit*: [226](#), [287](#), [288](#), [962](#), [963](#), [1302](#).
- \omit* primitive: [287](#).
- omit_error*: [1302](#), [1305](#).
- omit_template*: [180](#), [963](#), [964](#).
- one_bp*: [672](#), [687](#), [688](#), [693](#).
- one_hundred_bp*: [687](#), [688](#), [690](#), [692](#), [693](#), [792](#), [1634](#).
- one_hundred_inch*: [672](#), [687](#), [688](#), [1550](#).
- Only one # is allowed...*: [958](#).
- op_byte*: [571](#), [583](#), [705](#), [821](#), [915](#), [927](#), [1084](#),
[1086](#), [1216](#).
- op_noad*: [856](#), [864](#), [870](#), [872](#), [900](#), [902](#), [907](#), [923](#),
[935](#), [1332](#), [1333](#), [1335](#).
- op_start*: [1095](#), [1096](#), [1099](#), [1120](#), [1501](#).
- open_area*: [1519](#), [1529](#), [1600](#), [1619](#).
- open_ext*: [1519](#), [1529](#), [1600](#), [1619](#).
- open_fmt_file*: [550](#), [1515](#).
- \openin* primitive: [1448](#).
- open_log_file*: [78](#), [92](#), [382](#), [497](#), [558](#), [560](#), [561](#),
[563](#), [684](#), [1433](#), [1513](#).
- open_name*: [1519](#), [1529](#), [1600](#), [1619](#).
- open_noad*: [856](#), [864](#), [870](#), [872](#), [902](#), [907](#), [934](#),
[935](#), [936](#), [1332](#), [1333](#).
- open_node*: [1519](#), [1522](#), [1524](#), [1526](#), [1600](#), [1601](#),
[1602](#), [1617](#).
- open_node_size*: [1519](#), [1529](#), [1601](#), [1602](#).
- open_or_close_in*: [1450](#), [1451](#).
- \openout* primitive: [1522](#).
- open_parens*: [326](#), [353](#), [384](#), [563](#), [1513](#), [1752](#).
- open_subentries*: [788](#), [1634](#).
- \or* primitive: [517](#).
- or_code*: [515](#), [517](#), [518](#), [526](#), [535](#), [1469](#), [1665](#).
- ord*: [20](#).
- ord_noad*: [855](#), [856](#), [860](#), [861](#), [864](#), [870](#), [872](#), [902](#),
[903](#), [907](#), [926](#), [927](#), [935](#), [938](#), [939](#), [1251](#), [1331](#),
[1332](#), [1333](#), [1362](#).
- order*: [195](#).
- oriental characters*: [152](#), [612](#).
- orig_char_info*: [604](#), [705](#).
- other_A_token*: [471](#).
- other_char*: [225](#), [250](#), [311](#), [313](#), [316](#), [320](#), [369](#),
[471](#), [490](#), [552](#), [1110](#), [1136](#), [1205](#), [1213](#), [1266](#),
[1300](#), [1327](#), [1330](#), [1336](#).
- other_token*: [311](#), [431](#), [464](#), [467](#), [471](#), [490](#), [529](#),
[1241](#), [1397](#), [1758](#), [1766](#), [1781](#), [1782](#).
- othercases*: [10](#).
- others*: [10](#), [1617](#).
- Ouch...clobbered*: [1510](#).
- out_form*: [1634](#), [1641](#), [1644](#).
- out_image*: [1634](#), [1640](#), [1643](#).
- out_param*: [225](#), [311](#), [313](#), [316](#), [379](#).
- out_param_token*: [311](#), [505](#).
- out_thread*: [790](#), [1597](#).
- out_what*: [1610](#), [1611](#), [1617](#), [1620](#), [1636](#), [1642](#).
- \outer* primitive: [1384](#).
- outer_call*: [228](#), [297](#), [361](#), [373](#), [375](#), [376](#), [379](#), [388](#),
[413](#), [417](#), [422](#), [954](#), [1328](#), [1471](#), [1613](#).
- outer_doing_leaders*: [647](#), [656](#), [657](#), [665](#), [729](#),
[737](#), [738](#), [746](#).
- outline_list_count*: [1560](#), [1561](#).
- outlines*: [788](#), [804](#), [1511](#).
- output*: [4](#).
- Output loop...*: [1199](#).
- Output routine didn't use...*: [1203](#).
- Output written on x*: [670](#), [794](#).
- \output* primitive: [248](#).
- output_active*: [447](#), [837](#), [849](#), [1161](#), [1164](#), [1165](#),
[1169](#), [1180](#), [1200](#), [1201](#).
- output_file_name*: [558](#), [559](#), [670](#), [684](#), [794](#), [812](#), [813](#).
- output_group*: [291](#), [1200](#), [1276](#), [1658](#), [1676](#).
- output_one_char*: [726](#), [731](#).
- output_penalty*: [254](#).
- \outputpenalty* primitive: [256](#).
- output_penalty_code*: [254](#), [255](#), [256](#), [1188](#).
- output_routine*: [248](#), [1187](#), [1200](#).
- output_routine_loc*: [248](#), [249](#), [250](#), [329](#), [345](#), [1402](#).
- output_text*: [329](#), [336](#), [345](#), [1200](#), [1201](#).
- \over* primitive: [1354](#).
- over_code*: [1354](#), [1355](#), [1358](#).

over_noad: [861](#), [864](#), [870](#), [872](#), [907](#), [935](#), [1332](#).
`\overwithdelims` primitive: [1354](#).
overbar: [879](#), [908](#), [911](#).
overflow: [35](#), [42](#), [43](#), [94](#), [138](#), [143](#), [234](#), [279](#), [282](#),
[286](#), [295](#), [296](#), [343](#), [350](#), [400](#), [416](#), [543](#), [607](#), [678](#),
[680](#), [686](#), [698](#), [705](#), [706](#), [719](#), [725](#), [1115](#), [1119](#),
[1129](#), [1139](#), [1511](#), [1632](#), [1765](#), [1779](#).
overflow in arithmetic: [9](#), [104](#).
`Overfull \hbox...`: [840](#).
`Overfull \vbox...`: [851](#).
overfull boxes: [1028](#).
overfull_rule: [265](#), [840](#), [974](#), [978](#).
`\overfullrule` primitive: [266](#).
overfull_rule_code: [265](#), [266](#).
`\overline` primitive: [1332](#).
p: [112](#), [114](#), [138](#), [141](#), [143](#), [148](#), [149](#), [154](#), [157](#), [162](#),
[163](#), [165](#), [169](#), [170](#), [171](#), [172](#), [174](#), [176](#), [185](#), [190](#),
[192](#), [194](#), [196](#), [200](#), [216](#), [218](#), [219](#), [220](#), [222](#), [236](#),
[278](#), [281](#), [284](#), [285](#), [298](#), [299](#), [300](#), [301](#), [303](#), [306](#),
[314](#), [317](#), [321](#), [328](#), [337](#), [345](#), [347](#), [358](#), [388](#), [415](#),
[433](#), [439](#), [476](#), [490](#), [491](#), [499](#), [508](#), [523](#), [524](#),
[609](#), [634](#), [642](#), [647](#), [657](#), [666](#), [674](#), [693](#), [729](#),
[738](#), [821](#), [842](#), [853](#), [860](#), [862](#), [863](#), [865](#), [866](#),
[878](#), [879](#), [883](#), [885](#), [889](#), [890](#), [891](#), [894](#), [900](#),
[909](#), [912](#), [917](#), [923](#), [926](#), [930](#), [946](#), [948](#), [961](#),
[965](#), [973](#), [974](#), [1000](#), [1081](#), [1109](#), [1123](#), [1124](#),
[1128](#), [1132](#), [1134](#), [1135](#), [1141](#), [1143](#), [1145](#), [1168](#),
[1169](#), [1187](#), [1240](#), [1244](#), [1251](#), [1255](#), [1262](#), [1269](#),
[1277](#), [1281](#), [1286](#), [1289](#), [1295](#), [1299](#), [1314](#), [1327](#),
[1331](#), [1336](#), [1350](#), [1352](#), [1360](#), [1367](#), [1370](#), [1387](#),
[1412](#), [1420](#), [1464](#), [1469](#), [1478](#), [1479](#), [1526](#), [1527](#),
[1543](#), [1554](#), [1571](#), [1575](#), [1599](#), [1612](#), [1614](#), [1617](#),
[1632](#), [1633](#), [1634](#), [1676](#), [1680](#), [1716](#), [1720](#), [1730](#),
[1735](#), [1741](#), [1750](#), [1753](#), [1754](#), [1774](#), [1779](#), [1818](#),
[1820](#), [1834](#), [1835](#), [1836](#), [1837](#), [1838](#).
p_1: [1851](#).
pack_begin_line: [835](#), [836](#), [837](#), [849](#), [978](#), [989](#).
pack_buffered_name: [549](#), [550](#).
pack_cur_name: [555](#), [556](#), [563](#), [772](#), [1451](#), [1619](#).
pack_file_name: [545](#), [555](#), [563](#), [589](#), [713](#).
pack_job_name: [555](#), [558](#), [560](#), [684](#), [1506](#).
pack_lig: [1210](#).
package: [1261](#), [1262](#).
packed_ASCII_code: [38](#), [39](#), [793](#), [1122](#).
packet_byte: [725](#), [726](#).
packet_length: [712](#), [717](#), [719](#).
packet_read_signed: [725](#).
packet_read_unsigned: [725](#), [726](#).
packet_scaled: [725](#), [726](#).
page: [326](#), [1550](#).
page_contents: [447](#), [1155](#), [1161](#), [1162](#), [1166](#), [1175](#),
[1176](#), [1183](#).

page_depth: [1157](#), [1162](#), [1166](#), [1177](#), [1178](#), [1179](#),
[1183](#), [1185](#), [1608](#).
`\pagedepth` primitive: [1158](#).
page_disc: [1174](#), [1198](#), [1201](#), [1856](#), [1857](#).
`\pagediscards` primitive: [1858](#).
`\pagefilstretch` primitive: [1158](#).
`\pagefillstretch` primitive: [1158](#).
`\pagefilllstretch` primitive: [1158](#).
page_goal: [1155](#), [1157](#), [1161](#), [1162](#), [1180](#), [1181](#),
[1182](#), [1183](#), [1184](#), [1185](#).
`\pagegoal` primitive: [1158](#).
page_head: [180](#), [233](#), [1155](#), [1161](#), [1163](#), [1166](#), [1189](#),
[1192](#), [1198](#), [1201](#), [1230](#).
page_ins_head: [180](#), [498](#), [1156](#), [1161](#), [1180](#), [1183](#),
[1193](#), [1194](#), [1195](#).
page_ins_node_size: [1156](#), [1184](#), [1194](#).
page_loc: [666](#), [668](#).
page_max_depth: [1155](#), [1157](#), [1162](#), [1166](#), [1178](#),
[1192](#).
page_shrink: [1157](#), [1160](#), [1179](#), [1182](#), [1183](#), [1184](#).
`\pageshrink` primitive: [1158](#).
page_so_far: [447](#), [1157](#), [1160](#), [1162](#), [1179](#), [1182](#),
[1184](#), [1421](#).
page_stack: [326](#).
`\pagestretch` primitive: [1158](#).
page_tail: [233](#), [1155](#), [1161](#), [1166](#), [1173](#), [1175](#),
[1192](#), [1198](#), [1201](#), [1230](#).
page_total: [1157](#), [1160](#), [1177](#), [1178](#), [1179](#), [1182](#),
[1183](#), [1185](#), [1608](#).
`\pagetotal` primitive: [1158](#).
pagebox: [1550](#).
pages_tail: [696](#), [798](#), [800](#).
pages_tree_kids_max: [695](#), [770](#), [794](#), [800](#), [801](#).
panicking: [183](#), [184](#), [1206](#), [1517](#).
`\par` primitive: [356](#).
par_end: [225](#), [356](#), [357](#), [1222](#), [1270](#).
par_fill_skip: [242](#), [990](#), [1839](#), [1840](#), [1843](#), [1850](#).
`\parfillskip` primitive: [244](#).
par_fill_skip_code: [242](#), [243](#), [244](#), [990](#).
par_indent: [265](#), [1267](#), [1269](#).
`\parindent` primitive: [266](#).
par_indent_code: [265](#), [266](#).
par_loc: [355](#), [356](#), [373](#), [1489](#), [1490](#).
`\parshape` primitive: [287](#).
`\parshapedimen` primitive: [1669](#).
par_shape_dimen_code: [1669](#), [1670](#), [1671](#).
`\parshapeindent` primitive: [1669](#).
par_shape_indent_code: [1669](#), [1670](#), [1671](#).
`\parshapelength` primitive: [1669](#).
par_shape_length_code: [1669](#), [1670](#), [1671](#).
par_shape_loc: [248](#), [250](#), [251](#), [287](#), [288](#), [449](#),
[1246](#), [1424](#).

par_shape_ptr: [248](#), [250](#), [251](#), [449](#), [988](#), [1021](#), [1022](#),
[1024](#), [1064](#), [1246](#), [1325](#), [1425](#), [1671](#).
par_skip: [242](#), [1267](#).
\parskip primitive: [244](#).
par_skip_code: [242](#), [243](#), [244](#), [1267](#).
par_token: [355](#), [356](#), [361](#), [418](#), [421](#), [425](#), [1271](#), [1490](#).
Paragraph ended before...: [422](#).
param: [568](#), [573](#), [584](#).
param_base: [576](#), [578](#), [584](#), [592](#), [601](#), [602](#), [603](#), [605](#),
[607](#), [705](#), [706](#), [874](#), [875](#), [1218](#), [1498](#), [1499](#).
param_end: [584](#).
param_ptr: [330](#), [345](#), [346](#), [353](#), [416](#).
param_size: [11](#), [330](#), [416](#), [1512](#).
param_stack: [329](#), [330](#), [346](#), [381](#), [414](#), [415](#), [416](#).
param_start: [329](#), [345](#), [346](#), [381](#).
parameter: [329](#), [336](#), [381](#).
parameters for symbols: [874](#), [875](#).
Parameters...consecutively: [502](#).
parent_box: [1627](#), [1632](#), [1633](#), [1634](#).
Pascal-H: [3](#), [4](#), [9](#), [10](#), [27](#), [28](#), [33](#), [34](#).
Pascal: [1](#), [10](#), [867](#), [938](#).
pass_number: [995](#), [1019](#), [1038](#).
pass_text: [388](#), [520](#), [526](#), [535](#), [536](#).
passive: [995](#), [1019](#), [1020](#), [1038](#), [1039](#).
passive_node_size: [995](#), [1019](#), [1039](#).
Patterns can be...: [1428](#).
\patterns primitive: [1426](#).
pause_for_instructions: [96](#), [98](#).
pausing: [254](#), [385](#).
\pausing primitive: [256](#).
pausing_code: [254](#), [255](#), [256](#).
pc: [484](#).
pdf_action_file: [695](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_goto: [695](#), [1554](#), [1600](#), [1627](#).
pdf_action_id: [695](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_named_id: [695](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_new_window: [695](#), [1554](#), [1627](#).
pdf_action_page: [695](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_page_tokens: [695](#), [1534](#), [1554](#), [1600](#),
[1627](#).
pdf_action_refcount: [695](#), [1534](#), [1554](#).
pdf_action_size: [695](#), [1534](#), [1554](#).
pdf_action_thread: [695](#), [1554](#), [1600](#), [1627](#).
pdf_action_type: [695](#), [782](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_user: [695](#), [782](#), [1534](#), [1554](#), [1600](#), [1627](#).
pdf_action_user_tokens: [695](#), [1534](#), [1554](#), [1600](#),
[1627](#).
pdf_adjust_interword_glue: [254](#), [1205](#), [1217](#).
\pdfadjustinterwordglue primitive: [256](#).
pdf_adjust_interword_glue_code: [254](#), [255](#), [256](#).
pdf_adjust_spacing: [254](#), [997](#), [1001](#), [1015](#), [1016](#),
[1025](#), [1040](#), [1041](#), [1044](#), [1045](#), [1064](#).

\pdfadjustspacing primitive: [256](#).
pdf_adjust_spacing_code: [254](#), [255](#), [256](#).
\pdfannot primitive: [1522](#).
pdf_annot_data: [695](#), [781](#), [1556](#), [1600](#), [1601](#), [1602](#).
pdf_annot_list: [754](#), [765](#), [771](#), [781](#), [1625](#), [1627](#).
pdf_annot_node: [781](#), [1522](#), [1524](#), [1526](#), [1556](#),
[1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
pdf_annot_node_size: [695](#), [1556](#), [1558](#), [1601](#), [1602](#).
pdf_annot_objnum: [695](#), [1556](#), [1627](#).
pdf_append_kern: [254](#), [705](#).
\pdfappendkern primitive: [256](#).
pdf_append_kern_code: [254](#), [255](#), [256](#).
pdf_append_list: [693](#), [696](#), [698](#), [1627](#), [1632](#), [1633](#),
[1634](#), [1636](#), [1642](#).
pdf_append_list_arg: [696](#), [698](#).
pdf_append_list_end: [698](#).
pdf_bead_list: [754](#), [765](#), [771](#), [786](#), [1625](#), [1634](#).
pdf_begin_dict: [698](#), [699](#), [752](#), [762](#), [769](#), [772](#), [778](#),
[781](#), [782](#), [784](#), [789](#), [801](#), [803](#), [1597](#).
pdf_begin_obj: [698](#), [772](#), [784](#), [795](#).
pdf_begin_stream: [685](#), [699](#), [757](#), [772](#), [812](#).
pdf_begin_string: [693](#), [726](#).
pdf_begin_text: [693](#).
pdf_bottom: [695](#), [781](#), [782](#), [785](#), [1627](#), [1632](#), [1634](#).
pdf_box_spec_art: [696](#), [697](#), [1550](#).
pdf_box_spec_bleed: [696](#), [697](#), [1550](#).
pdf_box_spec_crop: [696](#), [697](#), [1550](#).
pdf_box_spec_media: [696](#), [697](#), [1550](#).
pdf_box_spec_trim: [696](#), [697](#), [1550](#).
pdf_buf: [680](#), [681](#), [685](#), [686](#), [698](#), [699](#), [772](#).
pdf_buf_size: [680](#), [681](#), [686](#), [698](#), [699](#).
\pdfcatalog primitive: [1522](#).
pdf_catalog_code: [1522](#), [1524](#), [1526](#).
pdf_catalog_openaction: [804](#), [1577](#), [1625](#), [1626](#).
pdf_catalog_toks: [804](#), [1577](#), [1625](#), [1626](#).
pdf_char_marked: [799](#).
pdf_char_used: [708](#).
pdf_check_obj: [497](#), [1543](#), [1544](#), [1547](#), [1552](#).
pdf_check_vf_cur_val: [497](#), [703](#), [720](#), [1585](#).
\pdfcolorstack primitive: [1522](#).
pdf_colorstack_cmd: [695](#), [727](#), [1537](#), [1600](#), [1601](#),
[1602](#).
pdf_colorstack_data: [695](#), [727](#), [1537](#), [1600](#), [1601](#),
[1602](#).
pdf_colorstack_getter_node_size: [695](#), [1537](#), [1601](#),
[1602](#).
\pdfcolorstackinit primitive: [494](#).
pdf_colorstack_init_code: [494](#), [495](#), [497](#), [498](#).
pdf_colorstack_node: [1522](#), [1524](#), [1526](#), [1537](#), [1600](#),
[1601](#), [1602](#), [1636](#), [1642](#).
pdf_colorstack_node_size: [695](#).

pdf_colorstack_setter_node_size: [695](#), [1537](#), [1601](#), [1602](#).
pdf_colorstack_stack: [695](#), [727](#), [1537](#), [1600](#).
pdf_compress_level: [254](#), [672](#), [673](#), [685](#), [698](#), [748](#).
\pdfcompresslevel primitive: [256](#).
pdf_compress_level_code: [254](#), [255](#), [256](#).
pdf_copy_font: [227](#), [287](#), [288](#), [439](#), [604](#), [1386](#), [1432](#).
\pdfcopyfont primitive: [287](#).
pdf_create_obj: [693](#), [698](#), [770](#), [802](#), [1542](#), [1546](#), [1550](#), [1553](#), [1561](#), [1633](#).
\pdfcreationdate primitive: [494](#).
pdf_creation_date_code: [494](#), [495](#), [497](#).
pdf_cur_form: [752](#), [756](#), [763](#), [775](#), [1620](#), [1625](#).
pdf_cur_Tm_a: [690](#), [691](#), [692](#), [693](#).
pdf_decimal_digits: [254](#), [672](#), [792](#).
\pdfdecimaldigits primitive: [256](#).
pdf_decimal_digits_code: [254](#), [255](#), [256](#).
pdf_delta_h: [690](#), [691](#), [692](#), [693](#).
pdf_depth: [695](#), [1547](#), [1552](#), [1554](#), [1563](#), [1598](#), [1600](#), [1601](#), [1603](#), [1604](#), [1608](#), [1609](#), [1627](#), [1632](#), [1633](#), [1634](#), [1640](#), [1641](#), [1643](#).
\pdfdest primitive: [1522](#).
pdf_dest_fit: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fitb: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fitbh: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fitbv: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fith: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fitr: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_fitv: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_id: [695](#), [1563](#), [1600](#), [1601](#), [1602](#), [1634](#).
pdf_dest_list: [754](#), [765](#), [784](#), [1625](#), [1634](#).
pdf_dest_margin: [265](#), [1634](#).
\pdfdestmargin primitive: [266](#).
pdf_dest_margin_code: [265](#), [266](#).
pdf_dest_named_id: [695](#), [784](#), [1563](#), [1600](#), [1601](#), [1602](#), [1634](#).
pdf_dest_names_ptr: [698](#), [802](#), [803](#), [1511](#), [1625](#), [1626](#).
pdf_dest_node: [695](#), [1522](#), [1524](#), [1526](#), [1563](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
pdf_dest_node_size: [695](#), [1563](#), [1601](#), [1602](#).
pdf_dest_objnum: [695](#).
pdf_dest_type: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_xyz: [695](#), [784](#), [1563](#), [1600](#), [1634](#).
pdf_dest_xyz_zoom: [695](#), [784](#), [1563](#), [1600](#).
pdf_doing_string: [691](#), [692](#), [693](#).
pdf_doing_text: [691](#), [693](#).
pdf_draftmode: [254](#), [672](#), [683](#), [748](#), [1515](#).
\pdfdraftmode primitive: [256](#).
pdf_draftmode_code: [254](#), [255](#), [256](#).
pdf_draftmode_option: [691](#), [1515](#).
pdf_draftmode_value: [691](#), [1515](#).

pdf_dummy_font: [691](#), [693](#), [697](#).
pdf_each_line_depth: [265](#), [1062](#), [1063](#).
\pdfeachlinedepth primitive: [266](#).
pdf_each_line_depth_code: [265](#), [266](#).
pdf_each_line_height: [265](#), [1062](#), [1063](#).
\pdfeachlineheight primitive: [266](#).
pdf_each_line_height_code: [265](#), [266](#).
pdf_end_dict: [698](#), [762](#), [769](#), [781](#), [782](#), [784](#), [788](#), [789](#), [801](#), [802](#), [803](#), [804](#), [805](#), [1597](#).
\pdfendlink primitive: [1522](#).
pdf_end_link_node: [1522](#), [1524](#), [1526](#), [1559](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
pdf_end_obj: [685](#), [698](#), [772](#), [784](#), [786](#), [790](#), [795](#), [1561](#), [1577](#).
pdf_end_stream: [685](#), [699](#), [760](#), [772](#), [812](#).
pdf_end_string: [692](#), [693](#).
pdf_end_string_nl: [692](#), [693](#).
pdf_end_text: [693](#), [760](#), [1634](#).
\pdfendthread primitive: [1522](#).
pdf_end_thread_node: [1522](#), [1524](#), [1526](#), [1567](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
pdf_error: [497](#), [597](#), [599](#), [683](#), [685](#), [686](#), [689](#), [693](#), [705](#), [706](#), [712](#), [720](#), [726](#), [727](#), [747](#), [748](#), [772](#), [784](#), [821](#), [1003](#), [1535](#), [1543](#), [1546](#), [1550](#), [1554](#), [1556](#), [1558](#), [1559](#), [1563](#), [1564](#), [1571](#), [1577](#), [1585](#), [1587](#), [1591](#), [1600](#), [1617](#), [1620](#), [1627](#), [1632](#), [1634](#), [1636](#), [1642](#).
\pdfescapehex primitive: [494](#).
pdf_escape_hex_code: [494](#), [495](#), [497](#).
\pdfescapename primitive: [494](#).
pdf_escape_name_code: [494](#), [495](#), [497](#).
\pdfescapestring primitive: [494](#).
pdf_escape_string_code: [494](#), [495](#), [497](#).
pdf_f: [691](#), [692](#), [693](#).
\pdffakespace primitive: [1522](#).
pdf_fake_space_node: [1522](#), [1524](#), [1526](#), [1594](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
pdf_file: [680](#), [684](#), [794](#).
\pdffiledump primitive: [494](#).
pdf_file_dump_code: [494](#), [495](#), [497](#).
\pdffilemoddate primitive: [494](#).
pdf_file_mod_date_code: [494](#), [495](#), [497](#).
\pdffilesize primitive: [494](#).
pdf_file_size_code: [494](#), [495](#), [497](#).
pdf_first_line_height: [265](#), [1062](#), [1063](#).
\pdffirstlineheight primitive: [266](#).
pdf_first_line_height_code: [265](#), [266](#).
pdf_first_outline: [788](#), [789](#), [1561](#), [1625](#), [1626](#).
pdf_fix_dest: [795](#), [796](#).
pdf_fix_thread: [1597](#).
pdf_flush: [680](#), [685](#), [794](#).
pdf_font_attr: [704](#), [799](#), [1587](#).

- `\pdffontattr` primitive: [1522](#).
- `pdf_font_attr_code`: [1522](#), [1524](#), [1526](#).
- `pdf_font_auto_expand`: [692](#), [693](#), [705](#), [712](#), [720](#), [819](#).
- `pdf_font_blink`: [192](#), [693](#), [705](#), [720](#), [819](#).
- `pdf_font_ef_base`: [705](#), [819](#).
- `pdf_font_elink`: [703](#), [705](#), [819](#).
- `\pdffontexpand` primitive: [1522](#).
- `pdf_font_expand_code`: [1522](#), [1524](#), [1526](#).
- `pdf_font_expand_ratio`: [192](#), [692](#), [705](#), [706](#), [712](#), [720](#), [819](#), [821](#).
- `pdf_font_kn_ac_base`: [705](#), [819](#).
- `pdf_font_kn_bc_base`: [705](#), [819](#).
- `pdf_font_kn_bs_base`: [705](#), [819](#).
- `pdf_font_list`: [693](#), [708](#), [750](#), [753](#), [764](#), [766](#), [775](#), [776](#), [777](#).
- `pdf_font_lp_base`: [705](#), [819](#).
- `pdf_font_map`: [693](#), [708](#).
- `\pdffontname` primitive: [494](#).
- `pdf_font_name_code`: [494](#), [495](#), [497](#), [498](#).
- `pdf_font_nobuiltin_tounicode`: [704](#), [1591](#).
- `pdf_font_num`: [498](#), [692](#), [693](#), [698](#), [708](#), [766](#), [799](#).
- `\pdffontobjnum` primitive: [494](#).
- `pdf_font_objnum_code`: [494](#), [495](#), [497](#), [498](#).
- `pdf_font_rp_base`: [705](#), [819](#).
- `pdf_font_sh_bs_base`: [705](#), [819](#).
- `pdf_font_shrink`: [705](#), [712](#), [819](#), [821](#).
- `pdf_font_size`: [690](#), [692](#), [693](#), [708](#).
- `\pdffontsize` primitive: [494](#).
- `pdf_font_size_code`: [494](#), [495](#), [497](#), [498](#).
- `pdf_font_st_bs_base`: [705](#), [819](#).
- `pdf_font_step`: [705](#), [706](#), [712](#), [819](#), [821](#).
- `pdf_font_stretch`: [705](#), [712](#), [819](#), [821](#).
- `pdf_font_type`: [703](#), [704](#), [705](#), [706](#), [712](#), [720](#), [726](#).
- `pdf_force_pagebox`: [254](#), [1550](#).
- `\pdfforcepagebox` primitive: [256](#).
- `pdf_force_pagebox_code`: [254](#), [255](#), [256](#).
- `pdf_gamma`: [254](#), [672](#), [683](#).
- `\pdfgamma` primitive: [256](#).
- `pdf_gamma_code`: [254](#), [255](#), [256](#).
- `pdf_gen_tounicode`: [254](#), [799](#).
- `\pdfgentounicode` primitive: [256](#).
- `pdf_gen_tounicode_code`: [254](#), [255](#), [256](#).
- `pdf_get_mem`: [678](#), [705](#), [1542](#), [1546](#), [1550](#), [1561](#), [1634](#).
- `\pdfglyphtounicode` primitive: [1522](#).
- `pdf_glyph_to_unicode_code`: [1522](#), [1524](#), [1526](#).
- `pdf_gone`: [680](#), [681](#), [685](#), [794](#).
- `pdf_h`: [690](#), [691](#), [692](#).
- `pdf_h_origin`: [265](#), [672](#), [755](#).
- `\pdfhorigin` primitive: [266](#).
- `pdf_h_origin_code`: [265](#), [266](#).
- `pdf_height`: [695](#), [1547](#), [1552](#), [1554](#), [1563](#), [1598](#), [1600](#), [1601](#), [1603](#), [1604](#), [1608](#), [1609](#), [1627](#), [1632](#), [1633](#), [1634](#), [1640](#), [1641](#).
- `pdf_hlist_out`: [727](#), [729](#), [733](#), [737](#), [738](#), [742](#), [746](#), [751](#), [1553](#).
- `pdf_ignored_dimen`: [237](#), [265](#), [853](#), [961](#), [1062](#), [1063](#), [1200](#), [1232](#), [1259](#), [1275](#), [1343](#), [1479](#).
- `\pdfignoreddimen` primitive: [266](#).
- `pdf_ignored_dimen_code`: [265](#), [266](#).
- `pdf_image_apply_gamma`: [254](#), [672](#), [683](#).
- `\pdfimageapplygamma` primitive: [256](#).
- `pdf_image_apply_gamma_code`: [254](#), [255](#), [256](#).
- `pdf_image_gamma`: [254](#), [672](#), [683](#).
- `\pdfimagegamma` primitive: [256](#).
- `pdf_image_gamma_code`: [254](#), [255](#), [256](#).
- `pdf_image_hicolor`: [254](#), [672](#), [683](#).
- `\pdfimagehicolor` primitive: [256](#).
- `pdf_image_hicolor_code`: [254](#), [255](#), [256](#).
- `pdf_image_procset`: [701](#), [750](#), [753](#), [768](#), [776](#), [777](#).
- `pdf_image_resolution`: [254](#), [672](#), [1550](#).
- `\pdfimageresolution` primitive: [256](#).
- `pdf_image_resolution_code`: [254](#), [255](#), [256](#).
- `pdf_include_chars`: [1585](#), [1586](#).
- `\pdfincludechars` primitive: [1522](#).
- `pdf_include_chars_code`: [1522](#), [1524](#), [1526](#).
- `pdf_inclusion_copy_font`: [254](#), [683](#).
- `\pdfinclusioncopyfonts` primitive: [256](#).
- `pdf_inclusion_copy_font_code`: [254](#), [255](#), [256](#).
- `pdf_inclusion_errorlevel`: [254](#), [1503](#), [1550](#).
- `\pdfinclusionerrorlevel` primitive: [256](#).
- `pdf_inclusion_errorlevel_code`: [254](#), [255](#), [256](#).
- `pdf_indirect`: [702](#), [1627](#).
- `pdf_indirect_ln`: [702](#), [756](#), [769](#), [770](#), [788](#), [789](#), [801](#), [802](#), [804](#), [812](#), [813](#), [1597](#).
- `\pdfinfo` primitive: [1522](#).
- `pdf_info_code`: [1522](#), [1524](#), [1526](#).
- `pdf_info_omit_date`: [254](#), [805](#).
- `\pdfinfoomitdate` primitive: [256](#).
- `pdf_info_omit_date_code`: [254](#), [255](#), [256](#).
- `pdf_info_toks`: [805](#), [1576](#), [1625](#), [1626](#).
- `pdf_init_font`: [693](#), [1585](#).
- `pdf_init_font_cur_val`: [497](#), [693](#), [703](#).
- `pdf_init_map_file`: [1515](#).
- `pdf_insert_fake_space`: [693](#), [1636](#), [1642](#).
- `\pdfinsertht` primitive: [494](#).
- `pdf_insert_ht_code`: [494](#), [495](#), [497](#), [498](#).
- `pdf_insert_interword_space`: [693](#).
- `pdf_int_entry`: [702](#), [1627](#).
- `pdf_int_entry_ln`: [702](#), [788](#), [789](#), [801](#), [812](#), [813](#).
- `pdf_int_pars`: [254](#).
- `\pdfinterwordspaceoff` primitive: [1522](#).

- pdf_interword_space_off_node*: [1522](#), [1524](#), [1526](#), [1593](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- `\pdfinterwordspaceon` primitive: [1522](#).
- pdf_interword_space_on_node*: [1522](#), [1524](#), [1526](#), [1592](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_last_annot*: [450](#), [1555](#), [1556](#).
- `\pdflastannot` primitive: [442](#).
- pdf_last_annot_code*: [442](#), [443](#), [450](#).
- pdf_last_byte*: [685](#), [696](#).
- pdf_last_f*: [691](#), [693](#).
- pdf_last_fs*: [691](#), [693](#).
- pdf_last_line_depth*: [265](#), [1062](#), [1063](#).
- `\pdflastlinedepth` primitive: [266](#).
- pdf_last_line_depth_code*: [265](#), [266](#).
- pdf_last_link*: [450](#), [1557](#), [1558](#).
- `\pdflastlink` primitive: [442](#).
- pdf_last_link_code*: [442](#), [443](#), [450](#).
- `\pdflastmatch` primitive: [494](#).
- pdf_last_match_code*: [494](#), [495](#), [497](#).
- pdf_last_obj*: [450](#), [1502](#), [1503](#), [1541](#), [1542](#), [1620](#).
- `\pdflastobj` primitive: [442](#).
- pdf_last_obj_code*: [442](#), [443](#), [450](#).
- pdf_last_outline*: [788](#), [789](#), [1561](#), [1625](#), [1626](#).
- pdf_last_page*: [696](#), [752](#), [769](#), [784](#), [1634](#).
- pdf_last_pages*: [696](#), [770](#), [794](#), [800](#), [801](#), [804](#), [1511](#).
- pdf_last_resources*: [750](#), [752](#), [756](#), [762](#), [769](#).
- pdf_last_stream*: [696](#), [752](#), [769](#).
- pdf_last_thread_id*: [1625](#), [1634](#).
- pdf_last_thread_named_id*: [1625](#), [1634](#).
- pdf_last_x_pos*: [450](#), [1568](#), [1618](#), [1638](#).
- `\pdflastxpos` primitive: [442](#).
- pdf_last_x_pos_code*: [442](#), [443](#), [450](#).
- pdf_last_xform*: [450](#), [1502](#), [1503](#), [1545](#), [1546](#), [1620](#).
- `\pdflastxform` primitive: [442](#).
- pdf_last_xform_code*: [442](#), [443](#), [450](#).
- pdf_last_ximage*: [450](#), [1502](#), [1503](#), [1548](#), [1550](#), [1620](#).
- `\pdflastximage` primitive: [442](#).
- pdf_last_ximage_code*: [442](#), [443](#), [450](#).
- pdf_last_ximage_colordepth*: [450](#), [1548](#), [1550](#).
- `\pdflastximagecolordepth` primitive: [442](#).
- pdf_last_ximage_colordepth_code*: [442](#), [443](#), [450](#).
- pdf_last_ximage_pages*: [450](#), [1548](#), [1550](#).
- `\pdflastximagepages` primitive: [442](#).
- pdf_last_ximage_pages_code*: [442](#), [443](#), [450](#).
- pdf_last_y_pos*: [450](#), [1568](#), [1618](#), [1638](#).
- `\pdflastypos` primitive: [442](#).
- pdf_last_y_pos_code*: [442](#), [443](#), [450](#).
- pdf_left*: [695](#), [781](#), [782](#), [784](#), [785](#), [1627](#), [1632](#), [1634](#).
- pdf_link_action*: [695](#), [782](#), [1558](#), [1600](#), [1601](#), [1602](#).
- pdf_link_attr*: [695](#), [782](#), [1554](#), [1600](#), [1601](#), [1602](#).
- pdf_link_list*: [754](#), [765](#), [771](#), [782](#), [783](#), [1625](#), [1632](#), [1633](#).
- pdf_link_margin*: [265](#), [1632](#), [1633](#).
- `\pdflinkmargin` primitive: [266](#).
- pdf_link_margin_code*: [265](#), [266](#).
- pdf_link_objnum*: [695](#), [1558](#), [1601](#), [1632](#).
- pdf_link_stack*: [729](#), [730](#), [1628](#), [1630](#), [1633](#).
- pdf_link_stack_ptr*: [730](#), [1628](#), [1630](#), [1631](#), [1632](#).
- pdf_link_stack_record*: [1629](#), [1630](#).
- pdf_link_stack_top*: [1628](#), [1632](#).
- `\pdfliteral` primitive: [1522](#).
- pdf_literal_data*: [695](#), [727](#), [1536](#), [1600](#), [1601](#), [1602](#).
- pdf_literal_mode*: [695](#), [727](#), [1536](#), [1600](#).
- pdf_literal_node*: [1522](#), [1524](#), [1526](#), [1536](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_lookup_list*: [700](#), [1634](#).
- pdf_major_version*: [254](#), [672](#), [683](#), [1503](#), [1550](#).
- `\pdfmajorversion` primitive: [256](#).
- pdf_major_version_code*: [254](#), [255](#), [256](#).
- `\pdfmapfile` primitive: [1522](#).
- pdf_map_file_code*: [1522](#), [1524](#), [1526](#).
- `\pdfmapline` primitive: [1522](#).
- pdf_map_line_code*: [1522](#), [1524](#), [1526](#).
- pdf_mark_char*: [686](#), [693](#), [799](#), [1585](#).
- `\pdfmatch` primitive: [494](#).
- pdf_match_code*: [494](#), [495](#), [497](#).
- pdf_max_link_level*: [1628](#), [1630](#), [1632](#).
- `\pdfmdfivesum` primitive: [494](#).
- pdf_mdfive_sum_code*: [494](#), [495](#), [497](#).
- pdf_mem*: [675](#), [676](#), [677](#), [678](#), [695](#), [705](#), [1502](#), [1503](#).
- pdf_mem_ptr*: [676](#), [677](#), [678](#), [1502](#), [1503](#), [1511](#).
- pdf_mem_size*: [676](#), [677](#), [678](#), [1502](#), [1503](#), [1511](#).
- pdf_minor_version*: [254](#), [672](#), [683](#), [1503](#), [1550](#).
- `\pdfminorversion` primitive: [256](#).
- `\pdfoptionpdfminorversion` primitive: [256](#).
- pdf_minor_version_code*: [254](#), [255](#), [256](#).
- pdf_move_chars*: [254](#), [692](#).
- `\pdfmovechars` primitive: [256](#).
- pdf_move_chars_code*: [254](#), [255](#), [256](#).
- `\pdfnames` primitive: [1522](#).
- pdf_names_code*: [1522](#), [1524](#), [1526](#).
- pdf_names_toks*: [802](#), [1578](#), [1625](#), [1626](#).
- pdf_new_dict*: [698](#), [752](#), [788](#), [802](#), [804](#), [805](#), [812](#), [1597](#).
- pdf_new_line_char*: [685](#), [686](#), [699](#).
- pdf_new_obj*: [698](#), [786](#), [790](#), [1561](#), [1577](#).
- pdf_new_objnum*: [698](#), [752](#), [800](#), [1556](#), [1558](#), [1627](#), [1632](#), [1634](#).
- pdf_new_Tm_a*: [692](#).
- `\pdfnobuiltintounicode` primitive: [1522](#).
- pdf_nobuiltin_tounicode_code*: [1522](#), [1524](#), [1526](#).
- `\pdfobj` primitive: [1522](#).
- pdf_obj_code*: [1522](#), [1524](#), [1526](#), [1620](#).
- pdf_obj_count*: [1502](#), [1503](#), [1542](#), [1625](#), [1626](#).

pdf_obj_list: [750](#), [753](#), [764](#), [773](#), [775](#), [776](#), [777](#),
[1541](#), [1625](#), [1636](#), [1642](#).
pdf_obj_objnum: [695](#), [1544](#), [1600](#), [1636](#), [1642](#).
pdf_objcompresslevel: [254](#), [672](#), [683](#).
\pdfobjcompresslevel primitive: [256](#).
pdf_objcompresslevel_code: [254](#), [255](#), [256](#).
pdf_objtype_max: [695](#).
pdf_offset: [680](#), [685](#), [698](#), [794](#), [811](#).
pdf_omit_charset: [254](#), [673](#).
\pdfomitcharset primitive: [256](#).
pdf_omit_charset_code: [254](#), [255](#), [256](#).
pdf_op_buf: [680](#), [681](#), [698](#).
pdf_op_buf_size: [679](#), [680](#), [681](#), [698](#).
pdf_op_ptr: [680](#), [681](#), [698](#).
pdf_option_always_use_pdfpagebox: [254](#), [1550](#).
\pdfoptionalwaysusepdfpagebox
primitive: [256](#).
pdf_option_always_use_pdfpagebox_code: [254](#), [255](#),
[256](#).
pdf_option_pdf_inclusion_errorlevel: [254](#), [1550](#).
\pdfoptionpdfinclusionerrorlevel
primitive: [256](#).
pdf_option_pdf_inclusion_errorlevel_code: [254](#),
[255](#), [256](#).
pdf_origin_h: [691](#), [692](#), [752](#), [780](#).
pdf_origin_v: [691](#), [692](#), [752](#), [780](#).
pdf_os: [698](#).
pdf_os_buf: [680](#), [686](#), [698](#), [699](#).
pdf_os_buf_size: [679](#), [680](#), [681](#), [686](#), [698](#).
pdf_os_cntr: [680](#), [681](#), [698](#), [1511](#).
pdf_os_cur_objnum: [680](#), [681](#), [698](#), [699](#).
pdf_os_enable: [680](#), [683](#), [698](#), [794](#), [813](#).
pdf_os_get_os_buf: [680](#), [686](#).
pdf_os_level: [698](#).
pdf_os_max_objs: [679](#), [698](#), [1511](#).
pdf_os_mode: [680](#), [681](#), [685](#), [698](#), [699](#).
pdf_os_objidx: [680](#), [698](#), [699](#), [1511](#).
pdf_os_objnum: [680](#), [698](#), [699](#).
pdf_os_objoff: [680](#), [698](#), [699](#).
pdf_os_prepare_obj: [698](#).
pdf_os_ptr: [680](#), [681](#), [698](#).
pdf_os_switch: [698](#), [794](#).
pdf_os_write_objstream: [698](#), [699](#), [794](#).
pdf_out: [680](#), [683](#), [685](#), [686](#), [690](#), [692](#), [693](#), [699](#),
[702](#), [756](#), [766](#), [767](#), [769](#), [772](#), [784](#), [785](#), [786](#), [790](#),
[795](#), [803](#), [806](#), [812](#), [1597](#), [1627](#), [1634](#).
pdf_out_bytes: [702](#), [812](#).
pdf_out_colorstack: [727](#), [1636](#), [1642](#).
pdf_out_colorstack_startpage: [727](#), [757](#).
pdf_out_literal: [727](#), [1636](#), [1642](#).
pdf_out_restore: [727](#), [1636](#), [1642](#).
pdf_out_save: [727](#), [1636](#), [1642](#).

pdf_out_setmatrix: [727](#), [1636](#), [1642](#).
\pdfoutline primitive: [1522](#).
pdf_outline_code: [1522](#), [1524](#), [1526](#).
pdf_output: [254](#), [747](#), [791](#), [1025](#), [1515](#), [1535](#), [1576](#),
[1577](#), [1579](#), [1580](#).
\pdfoutput primitive: [256](#).
pdf_output_code: [254](#), [255](#), [256](#).
pdf_output_option: [691](#), [1515](#).
pdf_output_value: [691](#), [1515](#).
pdf_page_attr: [248](#), [769](#).
\pdfpageattr primitive: [248](#).
pdf_page_attr_loc: [248](#), [249](#).
pdf_page_group_val: [680](#), [752](#), [769](#), [1634](#).
pdf_page_height: [265](#), [644](#), [755](#), [1597](#).
\pdfpageheight primitive: [266](#).
pdf_page_height_code: [265](#), [266](#).
\pdfpageref primitive: [494](#).
pdf_page_ref_code: [494](#), [495](#), [497](#), [498](#).
pdf_page_resources: [248](#), [763](#).
\pdfpageresources primitive: [248](#).
pdf_page_resources_loc: [248](#), [249](#).
pdf_page_width: [265](#), [644](#), [755](#), [1597](#).
\pdfpagewidth primitive: [266](#).
pdf_page_width_code: [265](#), [266](#).
pdf_pagebox: [254](#), [1550](#).
\pdfpagebox primitive: [256](#).
pdf_pagebox_code: [254](#), [255](#), [256](#).
pdf_pages_attr: [248](#), [801](#).
\pdfpagesattr primitive: [248](#).
pdf_pages_attr_loc: [248](#), [249](#).
pdf_parent_outline: [789](#), [1561](#), [1625](#), [1626](#).
pdf_pk_mode: [248](#), [792](#).
\pdfpkmode primitive: [248](#).
pdf_pk_mode_loc: [248](#), [249](#).
pdf_pk_resolution: [254](#), [792](#).
\pdfpkresolution primitive: [256](#).
pdf_pk_resolution_code: [254](#), [255](#), [256](#).
pdf_prepend_kern: [254](#), [705](#), [1210](#).
\pdfprependkern primitive: [256](#).
pdf_prepend_kern_code: [254](#), [255](#), [256](#).
pdf_print: [683](#), [686](#), [692](#), [693](#), [698](#), [699](#), [702](#),
[727](#), [756](#), [758](#), [766](#), [767](#), [768](#), [769](#), [771](#), [772](#),
[782](#), [784](#), [790](#), [801](#), [803](#), [806](#), [811](#), [812](#), [813](#),
[1597](#), [1627](#), [1634](#).
pdf_print_bp: [690](#), [692](#), [693](#), [756](#), [1597](#), [1634](#).
pdf_print_char: [686](#), [726](#).
pdf_print_fw_int: [702](#), [811](#).
pdf_print_info: [749](#), [794](#), [805](#).
pdf_print_int: [683](#), [686](#), [690](#), [693](#), [698](#), [699](#), [702](#),
[766](#), [767](#), [769](#), [771](#), [784](#), [790](#), [795](#), [801](#), [803](#),
[806](#), [812](#), [1597](#), [1627](#), [1634](#).
pdf_print_int_ln: [683](#), [686](#), [699](#), [811](#), [813](#).

- pdf_print_ln*: [685](#), [686](#), [692](#), [693](#), [698](#), [699](#), [727](#), [756](#), [758](#), [766](#), [767](#), [768](#), [769](#), [771](#), [772](#), [781](#), [782](#), [784](#), [786](#), [788](#), [790](#), [795](#), [801](#), [803](#), [804](#), [805](#), [806](#), [811](#), [812](#), [813](#), [1597](#), [1627](#), [1634](#).
- pdf_print_mag_bp*: [690](#), [693](#), [769](#), [784](#), [785](#).
- pdf_print_nl*: [683](#), [686](#), [693](#), [702](#), [812](#).
- pdf_print_octal*: [686](#).
- pdf_print_real*: [690](#), [692](#), [693](#), [758](#), [1634](#).
- pdf_print_rect_spec*: [784](#), [785](#), [786](#).
- pdf_print_resname_prefix*: [693](#), [766](#), [767](#), [1634](#).
- pdf_print_str*: [702](#), [803](#), [1627](#).
- pdf_print_str_ln*: [702](#), [1561](#).
- pdf_print_toks*: [727](#).
- pdf_print_toks_ln*: [727](#), [756](#), [763](#), [769](#), [772](#), [778](#), [781](#), [782](#), [789](#), [801](#), [802](#), [804](#), [812](#), [813](#), [1627](#).
- pdf_print_two*: [686](#).
- pdf_protrude_chars*: [254](#), [1025](#), [1055](#), [1061](#).
- \pdfprotrudechars* primitive: [256](#).
- pdf_protrude_chars_code*: [254](#), [255](#), [256](#).
- pdf_ptr*: [680](#), [681](#), [685](#), [686](#), [698](#), [699](#), [772](#).
- pdf_px_dimen*: [265](#), [481](#), [672](#).
- \pdfpxdimen* primitive: [266](#).
- pdf_px_dimen_code*: [265](#), [266](#).
- pdf_quick_out*: [680](#), [686](#), [699](#), [702](#).
- pdf_read_dummy_font*: [693](#).
- pdf_rectangle*: [693](#), [781](#), [782](#).
- \pdfrefobj* primitive: [1522](#).
- pdf_refobj_node*: [1522](#), [1524](#), [1526](#), [1544](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_refobj_node_size*: [695](#), [1544](#), [1601](#), [1602](#).
- \pdfrefxform* primitive: [1522](#).
- pdf_refxform_node*: [1003](#), [1522](#), [1524](#), [1526](#), [1547](#), [1600](#), [1601](#), [1602](#), [1603](#), [1604](#), [1605](#), [1606](#), [1608](#), [1609](#), [1634](#), [1636](#), [1642](#).
- pdf_refxform_node_size*: [695](#), [1547](#), [1601](#), [1602](#).
- \pdfrefximage* primitive: [1522](#).
- pdf_refximage_node*: [1003](#), [1522](#), [1524](#), [1526](#), [1552](#), [1600](#), [1601](#), [1602](#), [1603](#), [1604](#), [1605](#), [1606](#), [1608](#), [1609](#), [1634](#), [1636](#), [1642](#).
- pdf_refximage_node_size*: [695](#), [1552](#), [1601](#), [1602](#).
- pdf_resname_prefix*: [693](#), [708](#), [709](#), [792](#).
- \pdfrestore* primitive: [1522](#).
- pdf_restore_node*: [1522](#), [1524](#), [1526](#), [1540](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_restore_node_size*: [695](#), [1540](#), [1601](#), [1602](#).
- pdf_retval*: [450](#), [1542](#), [1581](#).
- \pdfretval* primitive: [442](#).
- pdf_retval_code*: [442](#), [443](#), [450](#).
- pdf_right*: [695](#), [781](#), [782](#), [785](#), [1627](#), [1632](#).
- pdf_room*: [680](#), [686](#), [699](#), [702](#).
- \pdfrunninglinkoff* primitive: [1522](#).
- pdf_running_link_off_node*: [1522](#), [1524](#), [1526](#), [1595](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- \pdfrunninglinkon* primitive: [1522](#).
- pdf_running_link_on_node*: [1522](#), [1524](#), [1526](#), [1596](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- \pdfsave* primitive: [1522](#).
- pdf_save_node*: [1522](#), [1524](#), [1526](#), [1539](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_save_node_size*: [695](#), [1539](#), [1601](#), [1602](#).
- pdf_save_offset*: [680](#), [685](#), [811](#), [813](#).
- \pdfsavepos* primitive: [1522](#).
- pdf_save_pos_node*: [1522](#), [1524](#), [1526](#), [1574](#), [1600](#), [1601](#), [1602](#), [1617](#), [1636](#), [1642](#).
- pdf_scan_ext_toks*: [496](#).
- pdf_seek_write_length*: [681](#), [685](#), [696](#).
- pdf_set_font*: [693](#).
- pdf_set_origin*: [692](#), [693](#).
- pdf_set_origin_temp*: [692](#), [693](#).
- pdf_set_rule*: [693](#), [726](#), [734](#), [743](#).
- pdf_set_textmatrix*: [692](#), [693](#).
- \pdfsetmatrix* primitive: [1522](#).
- pdf_setmatrix_data*: [695](#), [727](#), [1538](#), [1600](#), [1601](#), [1602](#).
- pdf_setmatrix_node*: [1522](#), [1524](#), [1526](#), [1538](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_setmatrix_node_size*: [695](#), [1538](#), [1601](#), [1602](#).
- \pdfshellescape* primitive: [442](#).
- pdf_shell_escape_code*: [442](#), [443](#), [450](#).
- pdf_ship_out*: [727](#), [749](#), [750](#), [775](#), [791](#), [1553](#), [1620](#), [1637](#).
- \pdfsnaprefpoint* primitive: [1522](#).
- pdf_snap_ref_point_node*: [1522](#), [1524](#), [1526](#), [1570](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_snapx_refpos*: [1568](#), [1639](#).
- \pdfsnappy* primitive: [1522](#).
- \pdfsnappycomp* primitive: [1522](#).
- pdf_snappy_comp_node*: [1143](#), [1175](#), [1522](#), [1524](#), [1526](#), [1573](#), [1600](#), [1601](#), [1602](#), [1634](#), [1636](#), [1642](#).
- pdf_snappy_node*: [1143](#), [1175](#), [1522](#), [1524](#), [1526](#), [1572](#), [1600](#), [1601](#), [1602](#), [1634](#), [1636](#), [1642](#).
- pdf_snappy_refpos*: [1568](#), [1634](#), [1639](#).
- pdf_special*: [727](#), [1636](#), [1642](#).
- \pdfstartlink* primitive: [1522](#).
- pdf_start_link_node*: [783](#), [1522](#), [1524](#), [1526](#), [1554](#), [1558](#), [1600](#), [1601](#), [1602](#), [1628](#), [1629](#), [1632](#), [1636](#), [1642](#).
- \pdfstartthread* primitive: [1522](#).
- pdf_start_thread_node*: [786](#), [1522](#), [1524](#), [1526](#), [1554](#), [1566](#), [1600](#), [1601](#), [1602](#), [1634](#), [1636](#), [1642](#).
- pdf_str_entry*: [702](#), [1627](#).
- pdf_str_entry_ln*: [702](#), [805](#).
- \pdfstrcmp* primitive: [494](#).

- pdf_strcmp_code*: [494](#), [495](#), [497](#), [498](#).
- pdf_stream_length*: [685](#), [696](#).
- pdf_stream_length_offset*: [685](#), [696](#).
- pdf_suppress_ptex_info*: [254](#), [673](#), [805](#).
- \pdfsuppressptexinfo* primitive: [256](#).
- pdf_suppress_ptex_info_code*: [254](#), [255](#), [256](#).
- pdf_suppress_warning_dup_dest*: [254](#), [1562](#).
- \pdfsuppresswarningdupdest* primitive: [256](#).
- pdf_suppress_warning_dup_dest_code*: [254](#), [255](#), [256](#).
- pdf_suppress_warning_dup_map*: [254](#), [673](#).
- \pdfsuppresswarningdupmap* primitive: [256](#).
- pdf_suppress_warning_dup_map_code*: [254](#), [255](#), [256](#).
- pdf_suppress_warning_page_group*: [254](#), [673](#).
- \pdfsuppresswarningpagegroup* primitive: [256](#).
- pdf_suppress_warning_page_group_code*: [254](#), [255](#), [256](#).
- pdf_text_procset*: [701](#), [750](#), [753](#), [766](#), [768](#), [776](#), [777](#).
- \pdfthread* primitive: [1522](#).
- pdf_thread_attr*: [695](#), [1554](#), [1600](#), [1601](#), [1602](#), [1634](#).
- pdf_thread_dp*: [739](#), [1625](#), [1634](#).
- pdf_thread_ht*: [1625](#), [1634](#).
- pdf_thread_id*: [695](#), [1564](#), [1600](#), [1601](#), [1602](#), [1634](#).
- pdf_thread_level*: [739](#), [1625](#), [1634](#).
- pdf_thread_margin*: [265](#), [1634](#).
- \pdfthreadmargin* primitive: [266](#).
- pdf_thread_margin_code*: [265](#), [266](#).
- pdf_thread_named_id*: [695](#), [1564](#), [1600](#), [1601](#), [1602](#), [1634](#).
- pdf_thread_node*: [1522](#), [1524](#), [1526](#), [1554](#), [1565](#), [1600](#), [1601](#), [1602](#), [1636](#), [1642](#).
- pdf_thread_node_size*: [695](#), [1565](#), [1566](#), [1601](#), [1602](#), [1634](#).
- pdf_thread_wd*: [1625](#), [1634](#).
- pdf_tj_start_h*: [691](#), [692](#), [693](#).
- pdf_toks*: [248](#).
- pdf_top*: [695](#), [781](#), [782](#), [784](#), [785](#), [1627](#), [1632](#), [1634](#).
- pdf_tracing_fonts*: [192](#), [254](#).
- \pdftracingfonts* primitive: [256](#).
- pdf_tracing_fonts_code*: [254](#), [255](#), [256](#).
- \pdftrailer* primitive: [1522](#).
- pdf_trailer_code*: [1522](#), [1524](#), [1526](#).
- \pdftrailerid* primitive: [1522](#).
- pdf_trailer_id_code*: [1522](#), [1524](#), [1526](#).
- pdf_trailer_id_toks*: [812](#), [813](#), [1580](#), [1625](#), [1626](#).
- pdf_trailer_toks*: [812](#), [813](#), [1579](#), [1625](#), [1626](#).
- \pdfunescapehex* primitive: [494](#).
- pdf_unescape_hex_code*: [494](#), [495](#), [497](#).
- pdf_unique_resname*: [254](#), [792](#).
- \pdfuniqueresname* primitive: [256](#).
- pdf_unique_resname_code*: [254](#), [255](#), [256](#).
- pdf_use_font*: [692](#), [693](#).
- pdf_v*: [691](#), [692](#), [693](#).
- pdf_v_origin*: [265](#), [672](#), [755](#).
- \pdfvorigin* primitive: [266](#).
- pdf_v_origin_code*: [265](#), [266](#).
- pdf_version_written*: [680](#), [681](#), [683](#).
- pdf_vlist_node*: [738](#).
- pdf_vlist_out*: [727](#), [728](#), [733](#), [737](#), [738](#), [742](#), [746](#), [751](#), [1553](#).
- pdf_warning*: [683](#), [686](#), [692](#), [705](#), [794](#), [795](#), [797](#), [799](#), [1535](#), [1542](#), [1550](#), [1562](#), [1597](#), [1632](#).
- pdf_width*: [695](#), [730](#), [1547](#), [1552](#), [1554](#), [1563](#), [1598](#), [1600](#), [1601](#), [1603](#), [1604](#), [1605](#), [1606](#), [1627](#), [1632](#), [1633](#), [1634](#), [1643](#), [1644](#).
- pdf_write_image*: [778](#), [779](#), [1620](#).
- pdf_write_obj*: [772](#), [773](#), [1620](#).
- pdf_x*: [691](#), [693](#), [784](#), [785](#), [1634](#).
- \pdfxform* primitive: [1522](#).
- pdf_xform_code*: [1522](#), [1524](#), [1526](#), [1620](#).
- pdf_xform_count*: [1502](#), [1503](#), [1546](#), [1625](#), [1626](#).
- pdf_xform_depth*: [752](#), [756](#), [1625](#), [1638](#).
- pdf_xform_height*: [752](#), [756](#), [1625](#), [1638](#).
- pdf_xform_list*: [750](#), [753](#), [764](#), [767](#), [775](#), [776](#), [777](#), [1625](#), [1634](#).
- \pdfxformname* primitive: [494](#).
- pdf_xform_name_code*: [494](#), [495](#), [497](#), [498](#).
- pdf_xform_objnum*: [695](#), [1547](#), [1600](#), [1634](#).
- pdf_xform_width*: [752](#), [756](#), [1625](#).
- \pdfximage* primitive: [1522](#).
- \pdfximagebbox* primitive: [494](#).
- pdf_ximage_bbox_code*: [494](#), [495](#), [497](#), [498](#).
- pdf_ximage_code*: [1522](#), [1524](#), [1526](#), [1620](#).
- pdf_ximage_count*: [1502](#), [1503](#), [1550](#), [1625](#), [1626](#).
- pdf_ximage_list*: [750](#), [753](#), [764](#), [767](#), [775](#), [776](#), [777](#), [779](#), [1625](#), [1634](#).
- pdf_ximage_objnum*: [695](#), [1552](#), [1600](#), [1634](#).
- pdf_y*: [691](#), [693](#), [784](#), [785](#), [1634](#).
- pdfassert*: [692](#), [693](#), [705](#), [712](#), [725](#), [730](#), [799](#), [823](#), [1632](#), [1633](#).
- pdfdraftmode*: [748](#).
- pdfmapfile*: [1588](#).
- pdfmapline*: [1589](#).
- pdfmem_bead_size*: [695](#), [1634](#).
- pdfmem_obj_size*: [695](#), [1542](#).
- pdfmem_outline_size*: [695](#), [1561](#).
- pdfmem_xform_size*: [695](#), [1546](#).
- pdfmem_ximage_size*: [695](#), [1550](#).
- pdfoutput*: [747](#).
- \pdfprimitive* primitive: [287](#).
- \pdfprimitive* primitive (internalized): [394](#).
- pdfsetmatrix*: [727](#).
- pdfshipoutbegin*: [757](#).

- pdfshipoutend*: 760.
PDFTEX: 2.
pdfTeX_banner: 2.
pdfTeX_banner: 498, 805, 809.
\pdfTeXbanner primitive: 494.
pdfTeX_banner_code: 494, 495, 497, 498.
pdfTeX_convert_codes: 494.
pdfTeX_first_dimen_code: 265.
pdfTeX_first_expand_code: 494.
pdfTeX_first_extension_code: 1522, 1617.
pdfTeX_first_integer_code: 254.
pdfTeX_first_loc: 248.
pdfTeX_first_rint_code: 442.
pdfTeX_last_dimen_code: 265.
pdfTeX_last_extension_code: 1522, 1617.
pdfTeX_last_item_codes: 442.
pdfTeX_revision: 2, 498, 806.
\pdfTeXrevision primitive: 494.
pdfTeX_revision_code: 494, 495, 497, 498.
pdfTeX_version: 2, 450, 806.
\pdfTeXversion primitive: 442.
pdfTeX_version_code: 442, 443, 450.
pdfTeX_version_string: 2.
pen: 900, 935, 941, 1051, 1065.
penalties: 1278.
penalties: 900, 941.
penalty: 175, 176, 212, 251, 450, 990, 1040, 1065, 1148, 1171, 1175, 1185, 1186, 1188, 1863.
\penalty primitive: 287.
penalty_node: 175, 176, 201, 220, 224, 450, 674, 904, 935, 941, 990, 991, 1003, 1011, 1030, 1040, 1053, 1074, 1143, 1148, 1171, 1175, 1185, 1186, 1188, 1283.
pg_field: 230, 231, 236, 237, 448, 1420.
pi: 1003, 1005, 1025, 1030, 1033, 1145, 1147, 1148, 1149, 1169, 1175, 1180, 1181.
pk_dpi: 792, 1625.
pk_scale_factor: 691, 792.
plain: 547, 550, 1509.
Plass, Michael Frederick: 2, 987.
Please type...: 382, 556.
Please use *\mathaccent*...: 1342.
PLtoTF: 587.
plus: 488.
point_token: 464, 466, 474, 478.
pointer: 133, 134, 136, 138, 141, 142, 143, 148, 149, 154, 157, 162, 163, 165, 169, 170, 171, 172, 174, 176, 183, 185, 190, 216, 218, 219, 220, 222, 230, 231, 236, 270, 274, 275, 278, 281, 285, 297, 298, 299, 300, 301, 303, 306, 317, 319, 321, 327, 328, 330, 345, 347, 355, 358, 388, 408, 414, 415, 433, 439, 476, 487, 489, 490, 491, 496, 499, 508, 515, 523, 524, 575, 586, 609, 619, 632, 634, 642, 647, 657, 666, 673, 680, 686, 693, 699, 700, 705, 706, 708, 727, 729, 738, 750, 772, 785, 791, 817, 819, 821, 827, 842, 853, 860, 862, 863, 865, 866, 878, 879, 880, 883, 885, 889, 890, 891, 893, 894, 896, 900, 908, 909, 910, 911, 912, 917, 923, 926, 930, 936, 944, 946, 948, 961, 965, 973, 974, 988, 995, 997, 1000, 1002, 1003, 1004, 1007, 1036, 1046, 1051, 1067, 1075, 1076, 1081, 1082, 1087, 1101, 1109, 1143, 1145, 1152, 1155, 1157, 1168, 1169, 1187, 1205, 1207, 1219, 1240, 1244, 1250, 1251, 1255, 1262, 1269, 1277, 1281, 1286, 1289, 1295, 1299, 1314, 1327, 1331, 1336, 1350, 1352, 1360, 1367, 1370, 1374, 1387, 1412, 1423, 1433, 1464, 1469, 1478, 1479, 1523, 1526, 1527, 1535, 1543, 1548, 1554, 1560, 1571, 1575, 1597, 1599, 1612, 1614, 1617, 1625, 1627, 1629, 1632, 1633, 1634, 1680, 1702, 1716, 1720, 1730, 1735, 1738, 1741, 1747, 1750, 1753, 1754, 1770, 1774, 1779, 1812, 1813, 1816, 1818, 1819, 1820, 1822, 1832, 1834, 1835, 1836, 1837, 1838, 1839, 1856.
pointer_node_size: 1817, 1818, 1834, 1838.
Poirot, Hercule: 1459.
pool_file: 47, 50, 51, 52, 53.
pool_name: 11, 51.
pool_pointer: 38, 39, 45, 46, 59, 60, 69, 70, 286, 433, 490, 491, 496, 539, 545, 629, 666, 686, 693, 702, 706, 749, 750, 793, 1104, 1109, 1535, 1585, 1612, 1750.
pool_ptr: 38, 39, 41, 42, 43, 44, 47, 52, 58, 70, 216, 279, 490, 491, 496, 497, 542, 551, 645, 686, 727, 1485, 1486, 1510, 1512, 1517, 1612, 1685, 1751.
pool_size: 11, 38, 42, 52, 58, 216, 551, 686, 727, 1486, 1512, 1517, 1612.
pop: 611, 612, 613, 617, 628, 635, 670, 719, 726.
pop_alignment: 946, 974.
pop_input: 344, 346, 351.
pop_lig_stack: 1085, 1086.
pop_link_level: 1632.
pop_LR: 1702, 1705, 1708, 1709, 1714, 1715, 1725, 1732, 1734, 1736.
pop_nest: 235, 970, 973, 986, 990, 1201, 1262, 1272, 1276, 1295, 1344, 1360, 1382, 1729.
pop_node: 1003.
pop_packet_state: 725.
positive: 107, 689.
post: 610, 612, 613, 617, 618, 670, 712.
post_break: 163, 193, 213, 220, 224, 674, 821, 1003, 1014, 1032, 1056, 1058, 1091, 1295.
post_disc_break: 1051, 1055, 1058.
post_display_penalty: 254, 1381, 1382.
\postdisplaypenalty primitive: 256.

post_display_penalty_code: [254](#), [255](#), [256](#).
post_line_break: [1050](#), [1051](#), [1702](#).
post_post: [612](#), [613](#), [617](#), [618](#), [670](#).
pre: [610](#), [612](#), [613](#), [645](#), [714](#).
pre_adjust_head: [180](#), [1063](#), [1064](#), [1252](#), [1261](#),
[1375](#), [1381](#).
pre_adjust_tail: [821](#), [823](#), [827](#), [828](#), [829](#), [970](#), [1063](#),
[1064](#), [1252](#), [1261](#), [1375](#).
pre_break: [163](#), [193](#), [213](#), [220](#), [224](#), [674](#), [821](#), [1003](#),
[1032](#), [1043](#), [1055](#), [1056](#), [1059](#), [1090](#), [1293](#), [1295](#).
pre_display_direction: [254](#), [1314](#), [1375](#), [1741](#).
\predisplaydirection primitive: [1654](#).
pre_display_direction_code: [254](#), [1321](#), [1654](#), [1656](#).
pre_display_penalty: [254](#), [1379](#), [1382](#).
\predisplaypenalty primitive: [256](#).
pre_display_penalty_code: [254](#), [255](#), [256](#).
pre_display_size: [265](#), [1314](#), [1321](#), [1324](#), [1379](#), [1730](#).
\predisplaysize primitive: [266](#).
pre_display_size_code: [265](#), [266](#), [1321](#).
pre_t: [1374](#), [1375](#), [1381](#).
preamble: [942](#), [948](#).
preamble: [944](#), [945](#), [946](#), [951](#), [960](#), [975](#), [978](#).
preamble of DVI file: [645](#).
precedes_break: [166](#), [1042](#), [1148](#), [1175](#).
prefix: [227](#), [1384](#), [1385](#), [1386](#), [1387](#), [1767](#).
prefixed_command: [1386](#), [1387](#), [1446](#).
prepare_mag: [310](#), [483](#), [645](#), [670](#), [690](#), [693](#), [752](#),
[758](#), [792](#), [1511](#).
prepend_nl: [686](#).
pretolerance: [254](#), [1002](#), [1037](#).
\pretolerance primitive: [256](#).
pretolerance_code: [254](#), [255](#), [256](#).
prev_active_width: [997](#).
prev_auto_breaking: [997](#).
prev_break: [995](#), [1019](#), [1020](#), [1051](#), [1052](#).
prev_char_p: [821](#), [823](#), [826](#), [997](#), [1001](#), [1015](#), [1016](#),
[1037](#), [1040](#), [1041](#), [1044](#), [1045](#).
prev_depth: [230](#), [231](#), [233](#), [444](#), [853](#), [949](#), [960](#),
[961](#), [1200](#), [1232](#), [1259](#), [1275](#), [1343](#), [1382](#),
[1418](#), [1419](#), [1479](#).
\prevdepth primitive: [442](#).
prev_dp: [1145](#), [1147](#), [1148](#), [1149](#), [1151](#), [1609](#).
prev_graf: [230](#), [231](#), [233](#), [234](#), [448](#), [988](#), [990](#), [1038](#),
[1051](#), [1063](#), [1065](#), [1267](#), [1325](#), [1376](#), [1418](#).
\prevgraf primitive: [287](#).
prev_legal: [997](#), [1037](#).
prev_p: [647](#), [648](#), [650](#), [729](#), [731](#), [732](#), [997](#), [1003](#),
[1036](#), [1037](#), [1040](#), [1041](#), [1042](#), [1043](#), [1143](#), [1144](#),
[1145](#), [1148](#), [1187](#), [1189](#), [1192](#), [1197](#), [1718](#), [1719](#).
prev_prev_legal: [997](#).
prev_prev_r: [1004](#), [1006](#), [1017](#), [1018](#), [1034](#).

prev_r: [1003](#), [1004](#), [1006](#), [1017](#), [1018](#), [1019](#), [1025](#),
[1028](#), [1034](#).
prev_rightmost: [498](#), [1003](#), [1055](#), [1543](#).
prev_s: [1036](#), [1069](#), [1071](#).
prim: [275](#), [276](#), [282](#), [1494](#), [1495](#).
prim_base: [275](#), [281](#).
prim_eq_level: [275](#), [286](#).
prim_eq_level_field: [275](#).
prim_eq_type: [275](#), [286](#), [394](#), [395](#), [527](#), [1221](#).
prim_eq_type_field: [275](#).
prim_eqtb: [286](#).
prim_eqtb_base: [240](#), [275](#), [284](#), [285](#), [395](#), [1221](#).
prim_equiv: [275](#), [286](#), [394](#), [395](#), [527](#), [1221](#).
prim_equiv_field: [275](#).
prim_is_full: [275](#), [282](#).
prim_lookup: [281](#), [286](#), [394](#), [395](#), [527](#), [1221](#).
prim_next: [275](#), [276](#), [281](#), [282](#).
prim_prime: [275](#), [281](#), [283](#).
prim_size: [240](#), [275](#), [276](#), [277](#), [282](#), [283](#), [1494](#), [1495](#).
prim_text: [275](#), [276](#), [281](#), [282](#), [284](#), [285](#).
prim_used: [275](#), [277](#), [282](#).
prim_val: [286](#).
primitive: [244](#), [248](#), [256](#), [266](#), [286](#), [287](#), [288](#), [320](#),
[356](#), [402](#), [410](#), [437](#), [442](#), [494](#), [513](#), [517](#), [579](#),
[954](#), [1158](#), [1228](#), [1234](#), [1247](#), [1264](#), [1283](#), [1290](#),
[1317](#), [1332](#), [1345](#), [1354](#), [1364](#), [1384](#), [1395](#),
[1398](#), [1406](#), [1426](#), [1430](#), [1438](#), [1448](#), [1453](#),
[1462](#), [1467](#), [1509](#), [1510](#), [1522](#), [1646](#), [1654](#), [1660](#),
[1663](#), [1666](#), [1669](#), [1672](#), [1681](#), [1683](#), [1686](#), [1689](#),
[1694](#), [1698](#), [1744](#), [1756](#), [1759](#), [1767](#), [1775](#), [1798](#),
[1802](#), [1806](#), [1858](#), [1861](#).
primitive_size: [275](#).
print: [54](#), [59](#), [60](#), [62](#), [63](#), [68](#), [70](#), [71](#), [73](#), [84](#), [85](#), [86](#),
[89](#), [91](#), [94](#), [95](#), [121](#), [192](#), [193](#), [195](#), [196](#), [200](#), [201](#),
[202](#), [203](#), [204](#), [205](#), [206](#), [208](#), [209](#), [210](#), [211](#), [213](#),
[215](#), [229](#), [236](#), [237](#), [243](#), [251](#), [252](#), [255](#), [265](#), [269](#),
[284](#), [285](#), [306](#), [310](#), [316](#), [320](#), [321](#), [328](#), [339](#), [340](#),
[345](#), [358](#), [360](#), [361](#), [385](#), [399](#), [421](#), [422](#), [424](#), [426](#),
[454](#), [480](#), [482](#), [485](#), [491](#), [498](#), [528](#), [535](#), [556](#), [560](#),
[562](#), [587](#), [593](#), [606](#), [608](#), [645](#), [666](#), [667](#), [670](#), [674](#),
[686](#), [693](#), [705](#), [706](#), [712](#), [714](#), [717](#), [727](#), [750](#), [772](#),
[794](#), [795](#), [797](#), [799](#), [834](#), [837](#), [840](#), [848](#), [849](#), [851](#),
[866](#), [868](#), [871](#), [897](#), [950](#), [1003](#), [1020](#), [1030](#), [1111](#),
[1143](#), [1153](#), [1160](#), [1161](#), [1162](#), [1175](#), [1181](#), [1186](#),
[1190](#), [1199](#), [1225](#), [1240](#), [1271](#), [1308](#), [1342](#), [1389](#),
[1408](#), [1413](#), [1433](#), [1435](#), [1437](#), [1471](#), [1472](#), [1474](#),
[1485](#), [1487](#), [1494](#), [1496](#), [1498](#), [1500](#), [1502](#), [1506](#),
[1512](#), [1513](#), [1516](#), [1517](#), [1524](#), [1562](#), [1597](#), [1598](#),
[1600](#), [1658](#), [1659](#), [1676](#), [1677](#), [1678](#), [1688](#), [1701](#),
[1710](#), [1752](#), [1762](#), [1771](#), [1773](#), [1774](#), [1820](#), [1849](#).
print_ASCII: [68](#), [192](#), [194](#), [320](#), [608](#), [674](#), [865](#), [897](#).
print_char: [58](#), [59](#), [60](#), [64](#), [65](#), [66](#), [67](#), [69](#), [70](#), [82](#),

- 91, 94, 95, 103, 132, 189, 190, 192, 193, 194, 195, 196, 202, 204, 205, 206, 207, 208, 209, 210, 211, 214, 236, 237, 241, 247, 251, 252, 253, 260, 269, 270, 273, 284, 288, 306, 307, 316, 318, 321, 328, 335, 339, 384, 411, 498, 535, 562, 563, 587, 608, 645, 666, 667, 670, 674, 750, 794, 865, 897, 1020, 1030, 1108, 1181, 1186, 1241, 1245, 1388, 1389, 1456, 1470, 1471, 1472, 1487, 1496, 1498, 1500, 1506, 1511, 1513, 1518, 1598, 1599, 1600, 1658, 1659, 1676, 1677, 1678, 1727, 1752, 1762, 1820.
- print_cmd_chr*: 241, 251, 288, 318, [320](#), 321, 345, 358, 444, 454, 529, 536, 1225, 1242, 1304, 1388, 1389, 1413, 1513, 1517, 1653, 1676, 1678, 1688, 1762, 1766, 1773, 1774, 1820.
- print_creation_date*: 807.
- print_cs*: [284](#), 315, 336, 427.
- print_current_string*: [70](#), 200, 866.
- print_delimiter*: [865](#), 870, 871.
- print_err*: [72](#), [73](#), 93, 94, 95, 98, 121, 310, 358, 360, 368, 396, 399, 421, 422, 424, 429, 434, 441, 444, 454, 459, 460, 461, 462, 463, 468, 471, 472, 480, 482, 485, 486, 497, 501, 502, 505, 512, 526, 529, 536, 556, 587, 604, 606, 669, 683, 686, 897, 950, 957, 958, 966, 1000, 1111, 1112, 1135, 1136, 1137, 1138, 1151, 1153, 1168, 1179, 1184, 1190, 1199, 1202, 1203, 1223, 1225, 1240, 1242, 1244, 1245, 1254, 1258, 1260, 1271, 1275, 1286, 1296, 1297, 1303, 1304, 1305, 1308, 1311, 1335, 1337, 1342, 1353, 1359, 1368, 1371, 1373, 1383, 1388, 1389, 1391, 1401, 1408, 1412, 1413, 1417, 1419, 1420, 1428, 1434, 1435, 1459, 1474, 1480, 1511, 1537, 1616, 1653, 1693, 1762, 1766, 1779, 1781, 1808.
- print_esc*: [63](#), 86, 192, 194, 201, 202, 205, 206, 207, 208, 209, 210, 212, 213, 214, 215, 243, 245, 247, 249, 251, 252, 253, 255, 257, 260, 265, 267, 269, 284, 285, 288, 314, 315, 316, 345, 357, 399, 403, 411, 443, 454, 495, 512, 514, 518, 526, 606, 865, 868, 869, 870, 871, 873, 950, 955, 966, 1030, 1111, 1135, 1136, 1153, 1159, 1161, 1184, 1190, 1203, 1229, 1235, 1241, 1245, 1248, 1265, 1271, 1275, 1284, 1291, 1296, 1305, 1308, 1311, 1319, 1333, 1342, 1355, 1365, 1368, 1385, 1389, 1396, 1399, 1407, 1417, 1420, 1427, 1431, 1439, 1449, 1454, 1463, 1468, 1471, 1498, 1513, 1524, 1599, 1600, 1647, 1655, 1656, 1661, 1664, 1667, 1670, 1673, 1676, 1678, 1682, 1684, 1687, 1688, 1690, 1695, 1697, 1699, 1745, 1757, 1760, 1761, 1762, 1768, 1774, 1776, 1799, 1803, 1820, 1829, 1830, 1859, 1862.
- print_fam_and_char*: [865](#), 866, 870.
- print_file_name*: [544](#), 556, 587, 794, 1498, 1600.
- print_font_and_char*: [194](#), 201, 211.
- print_font_identifier*: [192](#), 194, 674, 799.
- print_glue*: [195](#), 196, 203, 204.
- print_group*: [1658](#), 1659, 1676, 1771, 1774.
- print_hex*: [67](#), 865, 1399.
- print_ID*: [812](#), 813.
- print_ID_alt*: [812](#), 813.
- print_if_line*: [321](#), [1688](#), 1773, 1774.
- print_int*: [65](#), 84, 91, 94, 103, 132, 186, 187, 188, 189, 190, 192, 203, 206, 212, 213, 214, 236, 237, 245, 247, 249, 251, 252, 253, 257, 260, 267, 269, 273, 307, 310, 321, 335, 358, 426, 491, 498, 535, 562, 587, 606, 645, 666, 667, 670, 705, 706, 727, 750, 794, 795, 797, 834, 837, 841, 848, 849, 852, 865, 897, 1020, 1030, 1108, 1161, 1181, 1184, 1186, 1199, 1203, 1275, 1408, 1472, 1485, 1487, 1494, 1496, 1500, 1502, 1506, 1513, 1517, 1537, 1562, 1597, 1599, 1600, 1634, 1658, 1676, 1678, 1688, 1710, 1819, 1820.
- print_length_param*: [265](#), 267, 269.
- print_ln*: [57](#), 58, 59, 61, 62, 71, 86, 89, 90, 132, 200, 216, 236, 254, 263, 318, 328, 336, 339, 352, 382, 385, 427, 510, 560, 563, 666, 667, 683, 686, 693, 750, 795, 797, 799, 834, 837, 840, 841, 848, 849, 851, 852, 866, 1003, 1025, 1055, 1143, 1161, 1441, 1456, 1485, 1487, 1494, 1496, 1500, 1502, 1518, 1562, 1597, 1614, 1676, 1688, 1710, 1727, 1752, 1771, 1773, 1774.
- print_locs*: [185](#).
- print_mark*: [194](#), 214, 1562, 1600.
- print_meaning*: [318](#), 498, 1470.
- print_mod_date*: 808.
- print_mode*: [229](#), 236, 321, 1225.
- print_nl*: [62](#), [73](#), 82, 84, 85, 90, 186, 187, 188, 189, 190, 236, 237, 263, 273, 307, 310, 321, 328, 333, 335, 336, 345, 382, 426, 556, 560, 608, 666, 667, 669, 670, 693, 712, 714, 717, 727, 750, 772, 794, 834, 840, 841, 848, 851, 852, 1020, 1030, 1031, 1037, 1108, 1161, 1162, 1167, 1181, 1186, 1297, 1470, 1472, 1473, 1498, 1500, 1506, 1511, 1513, 1516, 1614, 1634, 1676, 1688, 1710, 1771, 1773, 1774.
- print_param*: [255](#), 257, 260.
- print_plus*: [1160](#).
- print_plus_end*: [1160](#).
- print_roman_int*: [69](#), 498.
- print_rule_dimen*: [194](#), 205, 1598, 1600.
- print_sa_num*: [1819](#), 1820, 1829, 1830.
- print_scaled*: [103](#), 121, 132, 192, 194, 195, 196, 201, 202, 206, 209, 210, 237, 269, 491, 498, 587, 693, 840, 851, 871, 1160, 1161, 1162,

1181, 1186, 1435, 1437, 1498, 1600, 1634, 1677, 1678, 1820, 1849.

print_size: [873](#), [897](#), [1407](#).

print_skip_param: [207](#), [243](#), [245](#), [247](#).

print_spec: [196](#), [206](#), [207](#), [208](#), [247](#), [491](#), [1600](#), [1634](#), [1820](#).

print_style: [864](#), [868](#), [1346](#).

print_subsidiary_data: [866](#), [870](#), [871](#).

print_the_digs: [64](#), [65](#), [67](#).

print_totals: [236](#), [1160](#), [1161](#), [1181](#).

print_two: [66](#), [562](#), [645](#).

print_word: [132](#), [1517](#).

print_write_whatsit: [1599](#), [1600](#).

printed_node: [995](#), [1030](#), [1031](#), [1032](#), [1038](#).

privileged: [1227](#), [1230](#), [1306](#), [1316](#).

Producer: [805](#).

producer_given: [805](#).

prompt_file_name: [556](#), [558](#), [561](#), [563](#), [684](#), [1506](#), [1619](#).

prompt_input: [71](#), [83](#), [87](#), [382](#), [385](#), [510](#), [556](#).

protected: [1767](#).

`\protected` primitive: [1767](#).

protected_token: [311](#), [415](#), [504](#), [1389](#), [1471](#), [1769](#).

prune_movements: [642](#), [647](#), [657](#).

prune_page_top: [1143](#), [1152](#), [1196](#).

pseudo: [54](#), [57](#), [58](#), [59](#), [338](#).

pseudo_close: [351](#), [1754](#), [1755](#).

pseudo_files: [1747](#), [1748](#), [1751](#), [1753](#), [1754](#), [1755](#).

pseudo_input: [384](#), [1753](#).

pseudo_start: [1746](#), [1749](#), [1750](#).

pstack: [414](#), [416](#), [422](#), [426](#).

pt: [479](#).

ptmp: [1051](#), [1055](#).

punct_noad: [856](#), [864](#), [870](#), [872](#), [902](#), [926](#), [935](#), [1332](#), [1333](#).

push: [611](#), [612](#), [613](#), [617](#), [619](#), [628](#), [635](#), [643](#), [647](#), [657](#), [719](#), [721](#), [726](#).

push_alignment: [946](#), [948](#).

push_input: [343](#), [345](#), [347](#), [350](#).

push_link_level: [1632](#).

push_LR: [1702](#), [1705](#), [1708](#), [1714](#), [1725](#), [1734](#), [1736](#).

push_math: [1312](#), [1315](#), [1321](#), [1329](#), [1348](#), [1350](#), [1367](#).

push_nest: [234](#), [948](#), [960](#), [961](#), [1200](#), [1259](#), [1267](#), [1275](#), [1293](#), [1295](#), [1312](#), [1343](#), [1376](#).

push_node: [1003](#).

push_packet_state: [725](#).

put: [26](#), [29](#), [1481](#).

put_LR: [1702](#), [1707](#).

put_rule: [612](#), [613](#), [661](#), [719](#), [726](#).

put_sa_ptr: [1816](#), [1828](#).

put1: [612](#), [710](#), [719](#), [726](#).

put2: [612](#).

put3: [612](#).

put4: [612](#).

px: [481](#).

q: [112](#), [114](#), [122](#), [141](#), [143](#), [148](#), [149](#), [162](#), [169](#), [170](#), [171](#), [185](#), [190](#), [220](#), [222](#), [236](#), [297](#), [314](#), [337](#), [358](#), [388](#), [415](#), [433](#), [439](#), [476](#), [487](#), [489](#), [490](#), [491](#), [499](#), [508](#), [523](#), [524](#), [634](#), [689](#), [700](#), [821](#), [879](#), [880](#), [883](#), [886](#), [894](#), [900](#), [908](#), [909](#), [910](#), [911](#), [912](#), [917](#), [923](#), [926](#), [930](#), [936](#), [965](#), [974](#), [1000](#), [1004](#), [1036](#), [1051](#), [1076](#), [1081](#), [1109](#), [1123](#), [1128](#), [1132](#), [1134](#), [1135](#), [1143](#), [1145](#), [1169](#), [1187](#), [1219](#), [1244](#), [1255](#), [1269](#), [1281](#), [1295](#), [1299](#), [1314](#), [1360](#), [1367](#), [1374](#), [1387](#), [1412](#), [1478](#), [1479](#), [1526](#), [1614](#), [1634](#), [1680](#), [1720](#), [1735](#), [1741](#), [1750](#), [1754](#), [1779](#), [1812](#), [1816](#), [1818](#), [1819](#), [1822](#), [1834](#).

qi: [130](#), [498](#), [571](#), [575](#), [590](#), [596](#), [600](#), [603](#), [609](#), [643](#), [648](#), [821](#), [927](#), [1082](#), [1083](#), [1086](#), [1088](#), [1098](#), [1133](#), [1134](#), [1156](#), [1183](#), [1184](#), [1209](#), [1210](#), [1213](#), [1214](#), [1216](#), [1276](#), [1327](#), [1331](#), [1336](#), [1341](#), [1485](#), [1501](#), [1668](#), [1751](#), [1766](#), [1853](#), [1855](#).

qo: [130](#), [177](#), [192](#), [194](#), [203](#), [206](#), [580](#), [596](#), [603](#), [629](#), [643](#), [648](#), [674](#), [821](#), [865](#), [882](#), [896](#), [897](#), [915](#), [926](#), [929](#), [1071](#), [1072](#), [1073](#), [1078](#), [1084](#), [1098](#), [1120](#), [1156](#), [1161](#), [1183](#), [1193](#), [1196](#), [1214](#), [1486](#), [1500](#), [1501](#), [1658](#), [1855](#).

qqqq: [128](#), [131](#), [132](#), [576](#), [580](#), [595](#), [600](#), [601](#), [710](#), [821](#), [857](#), [887](#), [915](#), [926](#), [1084](#), [1214](#), [1357](#), [1481](#), [1482](#), [1751](#), [1753](#).

quad: [573](#), [584](#), [673](#), [705](#), [706](#), [821](#), [1731](#).

quad_code: [573](#), [584](#).

quarterword: [128](#), [131](#), [162](#), [271](#), [286](#), [293](#), [298](#), [299](#), [301](#), [303](#), [320](#), [322](#), [345](#), [619](#), [855](#), [880](#), [883](#), [885](#), [886](#), [898](#), [912](#), [923](#), [1051](#), [1096](#), [1118](#), [1119](#), [1122](#), [1135](#), [1237](#), [1255](#), [1281](#), [1653](#), [1676](#), [1774](#), [1812](#), [1832](#), [1834](#).

`\quitvmode` primitive: [1264](#).

quotient: [1793](#), [1794](#).

qw: [586](#), [590](#), [596](#), [600](#), [603](#).

r: [108](#), [122](#), [141](#), [143](#), [149](#), [222](#), [236](#), [388](#), [415](#), [439](#), [491](#), [508](#), [524](#), [821](#), [842](#), [880](#), [894](#), [900](#), [926](#), [965](#), [974](#), [1003](#), [1036](#), [1051](#), [1076](#), [1128](#), [1141](#), [1143](#), [1145](#), [1169](#), [1187](#), [1255](#), [1281](#), [1299](#), [1336](#), [1374](#), [1412](#), [1526](#), [1553](#), [1614](#), [1730](#), [1741](#), [1750](#), [1753](#), [1779](#), [1796](#).

R_code: [165](#), [210](#), [1714](#), [1728](#).

r_count: [1087](#), [1089](#), [1093](#).

r_hyf: [1066](#), [1067](#), [1069](#), [1074](#), [1077](#), [1098](#), [1606](#), [1607](#).

r_type: [900](#), [901](#), [902](#), [903](#), [934](#), [940](#), [941](#).

radical: [226](#), [287](#), [288](#), [1222](#), [1338](#).

`\radical` primitive: [287](#).

- radical_noad*: [857](#), [864](#), [870](#), [872](#), [907](#), [935](#), [1339](#).
- radical_noad_size*: [857](#), [872](#), [935](#), [1339](#).
- radix*: [388](#), [464](#), [465](#), [466](#), [470](#), [471](#), [474](#).
- radix_backup*: [388](#).
- `\raise` primitive: [1247](#).
- Ramshaw, Lyle Harold: [565](#).
- random_seed*: [110](#), [450](#), [1515](#), [1583](#).
- `\pdfrandomseed` primitive: [442](#).
- random_seed_code*: [442](#), [443](#), [450](#).
- randoms*: [110](#), [124](#), [125](#), [126](#), [127](#).
- rbrace_ptr*: [415](#), [425](#), [426](#).
- rc*: [821](#).
- read*: [52](#), [53](#), [1516](#), [1517](#).
- `\read` primitive: [287](#).
- read_expand_font*: [705](#), [1533](#).
- read_file*: [506](#), [511](#), [512](#), [1451](#).
- read_font_info*: [586](#), [590](#), [673](#), [693](#), [705](#), [706](#), [712](#), [1216](#), [1433](#).
- read_image*: [1550](#).
- `\readline` primitive: [1756](#).
- read_ln*: [52](#).
- read_open*: [506](#), [507](#), [509](#), [511](#), [512](#), [527](#), [1451](#).
- read_sixteen*: [590](#), [591](#), [594](#).
- read_to_cs*: [227](#), [287](#), [288](#), [1386](#), [1401](#), [1756](#).
- read_toks*: [325](#), [508](#), [1401](#).
- ready_already*: [1509](#), [1510](#).
- real*: [3](#), [109](#), [128](#), [200](#), [204](#), [647](#), [657](#), [729](#), [738](#), [1299](#), [1301](#), [1634](#), [1720](#).
- real addition: [1301](#).
- real division: [832](#), [838](#), [847](#), [850](#), [984](#), [985](#), [1299](#), [1301](#).
- real multiplication: [132](#), [204](#), [653](#), [662](#), [735](#), [744](#), [983](#), [1301](#), [1635](#).
- real_font_type*: [703](#), [712](#).
- rebox*: [889](#), [918](#), [924](#).
- reconstitute*: [1080](#), [1081](#), [1088](#), [1090](#), [1091](#), [1092](#), [1207](#).
- recursion: [76](#), [78](#), [191](#), [198](#), [216](#), [220](#), [221](#), [388](#), [428](#), [433](#), [524](#), [553](#), [619](#), [646](#), [866](#), [893](#), [894](#), [899](#), [928](#), [1124](#), [1132](#), [1134](#), [1511](#), [1620](#), [1679](#).
- ref_count*: [415](#), [416](#), [427](#).
- ref_link_node*: [1629](#), [1632](#), [1633](#).
- reference counts: [168](#), [218](#), [219](#), [221](#), [297](#), [313](#), [329](#), [1817](#), [1818](#).
- reflected*: [643](#), [1719](#), [1735](#).
- register*: [227](#), [437](#), [438](#), [439](#), [1386](#), [1397](#), [1400](#), [1411](#), [1412](#), [1413](#), [1820](#), [1829](#), [1831](#).
- rejected_cur_p*: [997](#), [1037](#).
- rel_noad*: [856](#), [864](#), [870](#), [872](#), [902](#), [935](#), [941](#), [1332](#), [1333](#).
- rel_penalty*: [254](#), [856](#), [935](#).
- `\relpenalty` primitive: [256](#).
- rel_penalty_code*: [254](#), [255](#), [256](#).
- relax*: [225](#), [287](#), [288](#), [380](#), [395](#), [398](#), [430](#), [504](#), [532](#), [1221](#), [1400](#), [1781](#).
- `\relax` primitive: [287](#).
- rem_byte*: [571](#), [580](#), [583](#), [596](#), [882](#), [887](#), [914](#), [923](#), [927](#), [1086](#), [1216](#).
- remainder*: [104](#), [106](#), [107](#), [483](#), [484](#), [569](#), [570](#), [571](#), [890](#), [891](#).
- remove_item*: [226](#), [1280](#), [1283](#), [1284](#).
- remove_last_space*: [686](#), [790](#), [801](#), [803](#).
- remove_pdffile*: [1511](#).
- rep*: [572](#).
- replace_count*: [163](#), [193](#), [213](#), [674](#), [1003](#), [1014](#), [1032](#), [1043](#), [1056](#), [1057](#), [1093](#), [1256](#), [1296](#).
- report_illegal_case*: [1221](#), [1226](#), [1227](#), [1419](#), [1622](#).
- reset*: [26](#), [27](#), [33](#).
- reset_disc_width*: [1013](#), [1043](#).
- reset_OK*: [27](#).
- `\pdfresettimer` primitive: [1522](#).
- reset_timer_code*: [1522](#), [1524](#), [1526](#).
- restart*: [15](#), [143](#), [144](#), [286](#), [363](#), [368](#), [379](#), [381](#), [382](#), [384](#), [395](#), [406](#), [439](#), [466](#), [926](#), [927](#), [956](#), [959](#), [963](#), [1327](#), [1391](#), [1779](#), [1780](#), [1785](#).
- restore_active_width*: [997](#).
- restore_cur_string*: [496](#), [497](#).
- restore_old_value*: [290](#), [298](#), [304](#).
- restore_sa*: [290](#), [304](#), [1834](#).
- restore_trace*: [299](#), [305](#), [306](#), [1820](#).
- restore_zero*: [290](#), [298](#), [300](#).
- restrictedshell*: [450](#).
- result*: [45](#), [46](#).
- resume_after_display*: [974](#), [1375](#), [1376](#), [1382](#).
- reswitch*: [15](#), [363](#), [365](#), [374](#), [388](#), [394](#), [489](#), [647](#), [648](#), [729](#), [731](#), [821](#), [823](#), [824](#), [900](#), [902](#), [1109](#), [1110](#), [1204](#), [1205](#), [1211](#), [1221](#), [1314](#), [1323](#), [1327](#), [1550](#), [1719](#), [1720](#), [1721](#), [1724](#), [1762](#).
- return**: [15](#), [16](#).
- return_sign*: [122](#), [123](#).
- reverse*: [3](#), [1718](#), [1719](#), [1720](#).
- reversed*: [643](#), [1711](#), [1718](#).
- rewrite*: [26](#), [27](#), [33](#).
- rewrite_OK*: [27](#).
- rh*: [128](#), [131](#), [132](#), [136](#), [231](#), [237](#), [239](#), [252](#), [274](#), [275](#), [290](#), [859](#), [1096](#), [1133](#), [1814](#).
- right*: [693](#).
- `\right` primitive: [1364](#).
- right_brace*: [225](#), [311](#), [316](#), [320](#), [369](#), [379](#), [415](#), [468](#), [500](#), [503](#), [959](#), [1110](#), [1136](#), [1243](#), [1428](#), [1680](#).
- right_brace_limit*: [311](#), [347](#), [348](#), [418](#), [425](#), [426](#), [500](#), [503](#), [1680](#).
- right_brace_token*: [311](#), [361](#), [1241](#), [1303](#), [1402](#), [1615](#).

- right_delimiter*: [857](#), [871](#), [922](#), [1357](#), [1358](#).
- right_hyphen_min*: [254](#), [1267](#), [1376](#), [1621](#), [1622](#).
- \righthyphenmin* primitive: [256](#).
- right_hyphen_min_code*: [254](#), [255](#), [256](#).
- \rightmarginkern* primitive: [494](#).
- right_margin_kern_code*: [494](#), [495](#), [497](#), [498](#).
- right_noad*: [861](#), [864](#), [870](#), [872](#), [899](#), [901](#), [902](#), [934](#), [935](#), [936](#), [1360](#), [1364](#), [1367](#).
- right_ptr*: [632](#), [633](#), [634](#), [642](#).
- right_pw*: [821](#), [1003](#), [1055](#).
- right_side*: [173](#), [498](#), [821](#), [1055](#).
- right_skip*: [242](#), [1001](#), [1054](#), [1055](#), [1737](#), [1840](#).
- \rightskip* primitive: [244](#).
- right_skip_code*: [242](#), [243](#), [244](#), [498](#), [1055](#), [1060](#), [1737](#), [1743](#).
- right_to_left*: [643](#), [651](#), [654](#), [656](#), [660](#), [661](#), [665](#), [733](#), [736](#), [737](#), [742](#), [743](#), [746](#), [1711](#), [1712](#), [1731](#).
- rightskip*: [1055](#).
- right1*: [612](#), [613](#), [634](#), [637](#), [643](#), [706](#), [719](#), [726](#).
- right2*: [612](#), [637](#).
- right3*: [612](#), [637](#).
- right4*: [612](#), [637](#).
- rlink*: [142](#), [143](#), [144](#), [145](#), [147](#), [148](#), [149](#), [150](#), [163](#), [167](#), [182](#), [187](#), [946](#), [993](#), [995](#), [1487](#), [1488](#).
- \romannumeral* primitive: [494](#).
- roman_numeral_code*: [494](#), [495](#), [497](#), [498](#).
- root*: [804](#), [812](#), [813](#), [1511](#).
- round*: [3](#), [132](#), [204](#), [653](#), [662](#), [735](#), [744](#), [983](#), [1301](#), [1635](#).
- round_decimals*: [102](#), [103](#), [478](#).
- round_glue*: [653](#), [1723](#).
- round_xn_over_d*: [689](#), [690](#), [693](#), [705](#), [706](#), [821](#), [1634](#).
- rover*: [142](#), [143](#), [144](#), [145](#), [146](#), [147](#), [148](#), [149](#), [150](#), [182](#), [187](#), [1487](#), [1488](#).
- rp*: [820](#), [1003](#).
- \rpcode* primitive: [1430](#).
- rp_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- rt_hit*: [1081](#), [1082](#), [1085](#), [1086](#), [1208](#), [1210](#), [1215](#), [1216](#).
- rule*: [1548](#), [1550](#), [1554](#), [1563](#).
- rule_dp*: [619](#), [650](#), [652](#), [654](#), [659](#), [661](#), [663](#), [732](#), [734](#), [736](#), [741](#), [743](#), [745](#).
- rule_ht*: [619](#), [650](#), [652](#), [654](#), [659](#), [661](#), [662](#), [663](#), [664](#), [726](#), [732](#), [734](#), [736](#), [741](#), [743](#), [744](#), [745](#), [1634](#), [1635](#).
- rule_node*: [156](#), [157](#), [166](#), [193](#), [201](#), [220](#), [224](#), [650](#), [654](#), [659](#), [663](#), [732](#), [736](#), [741](#), [745](#), [823](#), [825](#), [843](#), [844](#), [904](#), [935](#), [979](#), [1015](#), [1016](#), [1040](#), [1044](#), [1045](#), [1143](#), [1148](#), [1175](#), [1250](#), [1263](#), [1297](#), [1323](#), [1548](#), [1634](#), [1722](#), [1730](#).
- rule_node_size*: [156](#), [157](#), [220](#), [224](#), [1730](#).
- rule_save*: [974](#), [978](#).
- rule_wd*: [619](#), [650](#), [652](#), [653](#), [654](#), [655](#), [659](#), [661](#), [663](#), [726](#), [732](#), [734](#), [735](#), [736](#), [741](#), [743](#), [745](#), [1696](#), [1719](#), [1722](#), [1725](#), [1726](#).
- rules aligning with characters: [616](#).
- run*: [1003](#).
- runaway*: [138](#), [328](#), [360](#), [422](#), [512](#).
- Runaway...*: [328](#).
- s*: [45](#), [46](#), [58](#), [59](#), [60](#), [62](#), [63](#), [93](#), [94](#), [95](#), [103](#), [108](#), [143](#), [148](#), [165](#), [195](#), [196](#), [281](#), [286](#), [306](#), [415](#), [433](#), [496](#), [499](#), [508](#), [555](#), [556](#), [586](#), [666](#), [693](#), [705](#), [727](#), [772](#), [805](#), [815](#), [821](#), [842](#), [862](#), [873](#), [880](#), [894](#), [900](#), [912](#), [965](#), [974](#), [1004](#), [1036](#), [1051](#), [1076](#), [1109](#), [1141](#), [1143](#), [1162](#), [1187](#), [1236](#), [1237](#), [1299](#), [1314](#), [1374](#), [1412](#), [1433](#), [1455](#), [1527](#), [1553](#), [1585](#), [1599](#), [1627](#), [1676](#), [1680](#), [1716](#), [1741](#), [1750](#), [1779](#), [1818](#), [1820](#).
- s_out*: [690](#), [693](#).
- sa_bot_mark*: [1822](#), [1825](#), [1827](#).
- sa_chain*: [290](#), [304](#), [1832](#), [1833](#), [1834](#), [1838](#).
- sa_def*: [1836](#), [1837](#).
- sa_def_box*: [1253](#), [1836](#).
- sa_define*: [1402](#), [1403](#), [1412](#), [1836](#).
- sa_destroy*: [1835](#), [1836](#), [1837](#), [1838](#).
- sa_dim*: [1817](#), [1820](#).
- sa_first_mark*: [1822](#), [1825](#), [1826](#), [1827](#).
- sa_index*: [1812](#), [1817](#), [1818](#), [1819](#), [1834](#), [1835](#), [1838](#).
- sa_int*: [453](#), [1413](#), [1817](#), [1818](#), [1820](#), [1834](#), [1836](#), [1837](#), [1838](#).
- sa_lev*: [1817](#), [1834](#), [1836](#), [1837](#), [1838](#).
- sa_level*: [290](#), [304](#), [1832](#), [1833](#), [1834](#).
- sa_loc*: [1834](#), [1838](#).
- sa_mark*: [1152](#), [1187](#), [1513](#), [1813](#), [1814](#).
- sa_null*: [1812](#), [1813](#), [1814](#), [1817](#).
- sa_num*: [1817](#), [1819](#).
- sa_ptr*: [441](#), [453](#), [1403](#), [1413](#), [1817](#), [1818](#), [1820](#), [1834](#), [1835](#), [1836](#), [1837](#), [1838](#).
- sa_ref*: [1817](#), [1818](#), [1834](#).
- sa_restore*: [304](#), [1838](#).
- sa_root*: [1487](#), [1488](#), [1813](#), [1815](#), [1816](#), [1818](#).
- sa_save*: [1834](#), [1836](#).
- sa_split_bot_mark*: [1822](#), [1823](#), [1824](#).
- sa_split_first_mark*: [1822](#), [1823](#), [1824](#).
- sa_top_mark*: [1822](#), [1825](#), [1826](#).
- sa_type*: [453](#), [1413](#), [1817](#), [1820](#), [1829](#).
- sa_used*: [1812](#), [1816](#), [1817](#), [1818](#), [1822](#).
- sa_w_def*: [1836](#), [1837](#).
- sa_word_define*: [1412](#), [1836](#).
- save_active_width*: [997](#).
- save_cond_ptr*: [524](#), [526](#), [535](#).
- save_cs_ptr*: [948](#), [951](#).
- save_cur_cs*: [433](#), [1535](#).

- save_cur.h*: [725](#).
- save_cur_string*: [496](#), [497](#).
- save_cur.v*: [725](#).
- save_cur_val*: [476](#), [481](#).
- save_def_ref*: [496](#), [497](#).
- save_font_list*: [750](#), [776](#), [777](#).
- save_for_after*: [302](#), [1447](#).
- save.h*: [647](#), [651](#), [655](#), [656](#), [657](#), [660](#), [665](#), [729](#), [737](#), [1718](#), [1719](#).
- save_image_procset*: [750](#), [776](#), [777](#).
- save_index*: [290](#), [296](#), [298](#), [302](#), [304](#), [1676](#), [1771](#), [1774](#), [1834](#).
- save_level*: [290](#), [291](#), [296](#), [298](#), [302](#), [304](#), [1676](#), [1774](#), [1834](#).
- save.link*: [1004](#), [1031](#).
- save_loc*: [647](#), [657](#).
- save_obj_list*: [750](#), [776](#), [777](#).
- save_pointer*: [1675](#), [1676](#), [1770](#).
- save_ptr*: [290](#), [293](#), [294](#), [295](#), [296](#), [298](#), [302](#), [304](#), [305](#), [307](#), [815](#), [978](#), [1262](#), [1275](#), [1276](#), [1293](#), [1296](#), [1318](#), [1329](#), [1344](#), [1348](#), [1350](#), [1362](#), [1370](#), [1480](#), [1676](#), [1771](#), [1774](#), [1834](#).
- save_scanner_status*: [388](#), [393](#), [394](#), [415](#), [496](#), [497](#), [520](#), [524](#), [527](#), [533](#), [1763](#).
- save_size*: [11](#), [129](#), [293](#), [295](#), [1512](#), [1675](#).
- save_split_top_skip*: [1187](#), [1189](#).
- save_stack*: [221](#), [290](#), [292](#), [293](#), [295](#), [296](#), [297](#), [298](#), [299](#), [303](#), [304](#), [305](#), [307](#), [322](#), [398](#), [515](#), [815](#), [942](#), [1238](#), [1247](#), [1307](#), [1316](#), [1326](#), [1329](#), [1517](#), [1675](#).
- save_style*: [894](#), [900](#), [928](#).
- save_tail*: [231](#), [233](#), [705](#), [1209](#), [1215](#).
- save_text_procset*: [750](#), [776](#), [777](#).
- save_type*: [290](#), [296](#), [298](#), [302](#), [304](#), [1834](#).
- save.v*: [647](#), [651](#), [656](#), [657](#), [660](#), [664](#), [665](#), [738](#), [742](#), [746](#), [1640](#), [1641](#).
- save_vbadness*: [1187](#), [1192](#).
- save_vf_nf*: [712](#), [715](#).
- save_vfuzz*: [1187](#), [1192](#).
- save_warning_index*: [415](#), [496](#), [497](#).
- save_xform_list*: [750](#), [776](#), [777](#).
- save_ximage_list*: [750](#), [776](#), [777](#).
- saved*: [296](#), [815](#), [978](#), [1259](#), [1262](#), [1275](#), [1276](#), [1293](#), [1295](#), [1318](#), [1329](#), [1344](#), [1348](#), [1350](#), [1362](#), [1370](#), [1658](#), [1659](#), [1676](#), [1677](#), [1678](#).
- saved_pdf_cur_form*: [774](#), [775](#).
- saved_pdf_gone*: [685](#).
- saving_hyph_codes*: [254](#), [1135](#).
- \savingshyphcodes* primitive: [1654](#).
- saving_hyph_codes_code*: [254](#), [1654](#), [1656](#).
- saving_vdiscards*: [254](#), [1152](#), [1174](#), [1856](#).
- \savingsdiscards* primitive: [1654](#).
- saving_vdiscards_code*: [254](#), [1654](#), [1656](#).
- sc*: [128](#), [131](#), [132](#), [153](#), [168](#), [177](#), [182](#), [231](#), [237](#), [265](#), [268](#), [269](#), [439](#), [446](#), [451](#), [576](#), [578](#), [580](#), [583](#), [584](#), [598](#), [600](#), [602](#), [607](#), [695](#), [705](#), [706](#), [874](#), [875](#), [949](#), [996](#), [997](#), [1006](#), [1017](#), [1018](#), [1022](#), [1024](#), [1034](#), [1035](#), [1064](#), [1218](#), [1325](#), [1382](#), [1423](#), [1424](#), [1429](#), [1671](#), [1817](#), [1839](#).
- scale_image*: [1550](#).
- scaled*: [101](#), [102](#), [103](#), [104](#), [105](#), [106](#), [107](#), [108](#), [110](#), [126](#), [128](#), [131](#), [165](#), [168](#), [174](#), [194](#), [195](#), [473](#), [474](#), [476](#), [479](#), [574](#), [575](#), [586](#), [597](#), [611](#), [619](#), [634](#), [643](#), [647](#), [657](#), [673](#), [687](#), [689](#), [690](#), [691](#), [692](#), [693](#), [705](#), [706](#), [708](#), [712](#), [722](#), [725](#), [729](#), [738](#), [816](#), [821](#), [842](#), [853](#), [878](#), [879](#), [880](#), [886](#), [889](#), [890](#), [891](#), [893](#), [900](#), [909](#), [910](#), [911](#), [912](#), [917](#), [923](#), [930](#), [936](#), [965](#), [974](#), [997](#), [1003](#), [1004](#), [1013](#), [1021](#), [1051](#), [1081](#), [1145](#), [1146](#), [1152](#), [1155](#), [1157](#), [1169](#), [1187](#), [1244](#), [1262](#), [1299](#), [1314](#), [1374](#), [1433](#), [1550](#), [1625](#), [1627](#), [1632](#), [1633](#), [1634](#), [1716](#), [1720](#), [1741](#), [1839](#), [1841](#).
- scaled*: [1434](#).
- scaled_base*: [265](#), [267](#), [269](#), [1400](#), [1413](#).
- scaled_out*: [687](#), [689](#), [690](#), [692](#), [693](#).
- scan_action*: [1554](#), [1558](#), [1561](#), [1577](#).
- scan_alt_rule*: [1550](#), [1554](#), [1563](#).
- scan_box*: [1249](#), [1260](#), [1417](#).
- scan_char_num*: [440](#), [452](#), [460](#), [1110](#), [1205](#), [1213](#), [1299](#), [1300](#), [1327](#), [1330](#), [1400](#), [1408](#), [1429](#), [1668](#), [1766](#).
- scan_delimiter*: [1336](#), [1339](#), [1358](#), [1359](#), [1367](#), [1368](#).
- scan_dimen*: [436](#), [466](#), [473](#), [474](#), [487](#), [488](#), [1237](#).
- scan_eight_bit_int*: [459](#), [1275](#).
- scan_expr*: [1777](#), [1778](#), [1779](#).
- scan_fifteen_bit_int*: [462](#), [1327](#), [1330](#), [1341](#), [1400](#).
- scan_file_name*: [287](#), [356](#), [552](#), [553](#), [563](#), [1433](#), [1451](#), [1529](#).
- scan_font_ident*: [441](#), [452](#), [497](#), [604](#), [605](#), [705](#), [706](#), [1410](#), [1429](#), [1585](#), [1587](#), [1591](#), [1668](#), [1766](#).
- scan_four_bit_int*: [461](#), [527](#), [604](#), [1410](#), [1451](#), [1528](#).
- scan_general_text*: [1679](#), [1680](#), [1685](#), [1750](#).
- scan_glue*: [436](#), [487](#), [956](#), [1236](#), [1404](#), [1414](#), [1571](#), [1784](#).
- scan_image*: [1550](#), [1551](#).
- scan_int*: [435](#), [436](#), [458](#), [459](#), [460](#), [461](#), [462](#), [463](#), [464](#), [466](#), [473](#), [474](#), [487](#), [497](#), [529](#), [530](#), [535](#), [605](#), [705](#), [706](#), [1279](#), [1401](#), [1404](#), [1408](#), [1414](#), [1416](#), [1419](#), [1420](#), [1422](#), [1424](#), [1429](#), [1434](#), [1528](#), [1537](#), [1542](#), [1544](#), [1547](#), [1550](#), [1552](#), [1554](#), [1556](#), [1561](#), [1563](#), [1564](#), [1573](#), [1583](#), [1622](#), [1671](#), [1766](#), [1782](#), [1808](#), [1863](#).
- scan_keyword*: [180](#), [433](#), [479](#), [480](#), [481](#), [482](#), [484](#), [488](#), [489](#), [497](#), [705](#), [706](#), [815](#), [1258](#), [1275](#), [1401](#), [1412](#), [1434](#), [1536](#), [1537](#), [1542](#), [1546](#), [1550](#), [1554](#), [1556](#), [1561](#), [1563](#), [1564](#), [1577](#).

- scan_left_brace*: [429](#), [499](#), [815](#), [959](#), [1109](#), [1135](#),
[1200](#), [1275](#), [1293](#), [1295](#), [1329](#), [1348](#), [1350](#), [1680](#).
scan_math: [1326](#), [1327](#), [1334](#), [1339](#), [1341](#), [1352](#).
scan_mu_glue: [1782](#), [1783](#), [1784](#), [1804](#).
scan_normal_dimen: [474](#), [489](#), [529](#), [815](#), [1249](#),
[1258](#), [1358](#), [1359](#), [1404](#), [1414](#), [1419](#), [1421](#), [1423](#),
[1424](#), [1429](#), [1435](#), [1550](#), [1766](#), [1782](#).
scan_normal_glue: [1782](#), [1783](#), [1784](#), [1800](#), [1801](#),
[1805](#).
scan_optional_equals: [431](#), [705](#), [706](#), [956](#), [1400](#),
[1402](#), [1404](#), [1408](#), [1410](#), [1412](#), [1417](#), [1419](#), [1420](#),
[1421](#), [1422](#), [1423](#), [1424](#), [1429](#), [1433](#), [1451](#), [1529](#).
scan_pdf_box_spec: [1550](#).
scan_pdf_ext_toks: [497](#), [703](#), [1535](#), [1536](#), [1537](#),
[1538](#), [1542](#), [1546](#), [1550](#), [1554](#), [1556](#), [1561](#),
[1563](#), [1564](#), [1576](#), [1577](#), [1578](#), [1579](#), [1580](#),
[1585](#), [1587](#), [1588](#), [1589](#).
scan_register_num: [412](#), [441](#), [446](#), [453](#), [497](#), [531](#),
[1255](#), [1258](#), [1277](#), [1286](#), [1400](#), [1402](#), [1403](#), [1413](#),
[1417](#), [1423](#), [1472](#), [1546](#), [1807](#), [1808](#).
scan_rule_spec: [489](#), [1232](#), [1260](#).
scan_something_internal: [435](#), [436](#), [439](#), [458](#), [466](#),
[475](#), [477](#), [481](#), [487](#), [491](#), [1777](#).
scan_spec: [815](#), [942](#), [948](#), [1247](#), [1259](#), [1343](#).
scan_special: [693](#), [695](#), [726](#), [727](#).
scan_thread_id: [1564](#), [1565](#), [1566](#).
scan_tokens: [1744](#).
\scantokens primitive: [1744](#).
scan_toks: [313](#), [490](#), [499](#), [1135](#), [1277](#), [1394](#), [1402](#),
[1455](#), [1464](#), [1530](#), [1532](#), [1535](#), [1615](#), [1679](#).
scan_twenty_seven_bit_int: [463](#), [1327](#), [1330](#), [1336](#).
scanned_result: [439](#), [440](#), [441](#), [444](#), [448](#), [451](#),
[452](#), [454](#).
scanned_result_end: [439](#).
scanner_status: [327](#), [328](#), [353](#), [358](#), [361](#), [388](#), [393](#),
[394](#), [415](#), [417](#), [496](#), [497](#), [499](#), [508](#), [520](#), [524](#),
[527](#), [533](#), [951](#), [963](#), [1221](#), [1680](#), [1763](#).
\scriptfont primitive: [1406](#).
script_mlist: [863](#), [869](#), [872](#), [905](#), [1350](#).
\scriptscriptfont primitive: [1406](#).
script_script_mlist: [863](#), [869](#), [872](#), [905](#), [1350](#).
script_script_size: [873](#), [930](#), [1371](#), [1406](#).
script_script_style: [862](#), [868](#), [905](#), [1345](#).
\scriptscriptstyle primitive: [1345](#).
script_size: [873](#), [930](#), [1371](#), [1406](#).
script_space: [265](#), [931](#), [932](#), [933](#).
\scriptspace primitive: [266](#).
script_space_code: [265](#), [266](#).
script_style: [862](#), [868](#), [876](#), [877](#), [905](#), [930](#), [940](#),
[1345](#).
\scriptstyle primitive: [1345](#).
scripts_allowed: [861](#), [1352](#).
scroll_mode: [71](#), [73](#), [84](#), [86](#), [93](#), [556](#), [1438](#),
[1439](#), [1457](#).
\scrollmode primitive: [1438](#).
search_mem: [183](#), [190](#), [273](#), [1517](#).
second_indent: [1021](#), [1022](#), [1023](#), [1064](#).
second_pass: [1002](#), [1037](#), [1040](#).
second_width: [1021](#), [1022](#), [1023](#), [1024](#), [1064](#).
seconds_and_micros: [1553](#), [1582](#), [1584](#).
Sedgewick, Robert: [2](#).
see the transcript file...: [1513](#).
seed: [125](#).
selector: [54](#), [55](#), [57](#), [58](#), [59](#), [62](#), [71](#), [75](#), [86](#), [90](#),
[92](#), [98](#), [263](#), [333](#), [334](#), [338](#), [382](#), [491](#), [496](#),
[560](#), [561](#), [645](#), [666](#), [686](#), [705](#), [706](#), [712](#), [727](#),
[1433](#), [1441](#), [1455](#), [1474](#), [1506](#), [1511](#), [1513](#),
[1612](#), [1614](#), [1685](#), [1750](#).
semi_simple_group: [291](#), [1239](#), [1241](#), [1244](#), [1245](#),
[1658](#), [1676](#).
serial: [995](#), [1019](#), [1020](#), [1030](#).
set_aux: [227](#), [439](#), [442](#), [443](#), [444](#), [1386](#), [1418](#).
set_box: [227](#), [287](#), [288](#), [1386](#), [1417](#).
\setbox primitive: [287](#).
set_box_allowed: [76](#), [77](#), [1417](#), [1446](#).
set_box_dimen: [227](#), [439](#), [442](#), [443](#), [1386](#), [1418](#).
set_box_lr: [643](#), [981](#), [982](#), [1370](#), [1378](#), [1711](#), [1718](#).
set_box_lr_end: [643](#).
set_break_width_to_background: [1011](#).
set_char_and_font: [705](#).
set_char_0: [612](#), [613](#), [648](#), [719](#), [726](#).
set_conversion: [484](#).
set_conversion_end: [484](#).
set_cur_lang: [1109](#), [1135](#), [1267](#), [1376](#).
set_cur_r: [1083](#), [1085](#), [1086](#).
set_ef_code: [705](#), [1429](#).
set_expand_params: [705](#), [712](#).
set_ff: [498](#), [693](#), [696](#), [698](#), [766](#).
set_font: [227](#), [439](#), [579](#), [604](#), [706](#), [1386](#), [1393](#),
[1433](#), [1437](#).
set_glue_ratio_one: [109](#), [838](#), [850](#), [984](#), [985](#).
set_glue_ratio_zero: [109](#), [154](#), [831](#), [832](#), [838](#), [846](#),
[847](#), [850](#), [984](#), [985](#).
set_height_zero: [1145](#).
set_hyph_index: [1066](#), [1109](#), [1607](#), [1855](#).
set_image_group_ref: [1634](#).
set_interaction: [227](#), [1386](#), [1438](#), [1439](#), [1440](#).
set_job_id: [792](#).
set_kn_ac_code: [705](#), [1429](#).
set_kn_bc_code: [705](#), [1429](#).
set_kn_bs_code: [705](#), [1429](#).
\setlanguage primitive: [1522](#).
set_language_code: [1522](#), [1524](#), [1526](#).
set_lc_code: [1071](#), [1072](#), [1073](#), [1112](#), [1855](#).

- set_lp_code*: [705](#), [1429](#).
- set_math_char*: [1330](#), [1331](#).
- set_no_ligatures*: [705](#), [706](#), [1429](#).
- set_obj_fresh*: [695](#), [698](#), [810](#).
- set_obj_scheduled*: [695](#), [1627](#), [1632](#).
- set_origin*: [497](#), [693](#), [695](#), [727](#), [1536](#), [1600](#).
- set_page_dimen*: [227](#), [439](#), [1157](#), [1158](#), [1159](#), [1386](#), [1418](#).
- set_page_int*: [227](#), [439](#), [442](#), [443](#), [1386](#), [1418](#), [1689](#).
- set_page_so_far_zero*: [1162](#).
- set_prev_graf*: [227](#), [287](#), [288](#), [439](#), [1386](#), [1418](#).
- set_random_seed_code*: [1522](#), [1524](#), [1526](#).
- `\pdfsetrandomseed` primitive: [1522](#).
- set_rect_dims*: [1627](#), [1632](#), [1633](#), [1634](#).
- set_rp_code*: [705](#), [1429](#).
- set_rule*: [610](#), [612](#), [613](#), [652](#), [719](#), [726](#).
- set_sa_box*: [1818](#).
- set_sh_bs_code*: [705](#), [1429](#).
- set_shape*: [227](#), [251](#), [287](#), [288](#), [439](#), [1386](#), [1424](#), [1861](#).
- set_st_bs_code*: [705](#), [1429](#).
- set_tag_code*: [705](#), [1429](#).
- set_trick_count*: [338](#), [339](#), [340](#), [342](#).
- set1*: [612](#), [613](#), [648](#), [706](#), [719](#), [726](#).
- set2*: [612](#).
- set3*: [612](#).
- set4*: [612](#).
- sf_code*: [248](#), [250](#), [1209](#).
- `\sfcode` primitive: [1406](#).
- sf_code_base*: [248](#), [253](#), [1406](#), [1407](#), [1409](#).
- sh*: [705](#).
- `\shbscode` primitive: [1430](#).
- sh_bs_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- shape_ref*: [228](#), [250](#), [297](#), [1246](#), [1424](#).
- shellenabledp*: [450](#).
- shift_amount*: [153](#), [154](#), [177](#), [202](#), [651](#), [656](#), [660](#), [665](#), [733](#), [737](#), [742](#), [746](#), [821](#), [825](#), [842](#), [844](#), [855](#), [880](#), [894](#), [911](#), [912](#), [923](#), [924](#), [930](#), [931](#), [933](#), [973](#), [980](#), [981](#), [982](#), [1064](#), [1252](#), [1257](#), [1301](#), [1731](#), [1737](#), [1741](#), [1742](#), [1743](#).
- shift_case*: [1461](#), [1464](#).
- shift_down*: [917](#), [918](#), [919](#), [920](#), [921](#), [923](#), [925](#), [930](#), [931](#), [933](#).
- shift_up*: [917](#), [918](#), [919](#), [920](#), [921](#), [923](#), [925](#), [930](#), [932](#), [933](#).
- ship_out*: [619](#), [727](#), [750](#), [791](#), [814](#), [981](#), [982](#), [1198](#), [1251](#), [1645](#), [1697](#), [1702](#).
- `\shipout` primitive: [1247](#).
- ship_out_flag*: [1247](#), [1251](#), [1678](#).
- shipping_page*: [750](#), [751](#), [752](#), [757](#), [759](#), [760](#), [763](#), [1637](#).
- short_display*: [191](#), [192](#), [193](#), [211](#), [674](#), [837](#), [1031](#), [1517](#).
- short_display_n*: [674](#), [821](#), [1003](#), [1025](#), [1055](#).
- short_real*: [109](#), [128](#).
- shortcut*: [473](#), [474](#).
- shortfall*: [1004](#), [1025](#), [1026](#), [1027](#), [1839](#), [1844](#), [1846](#), [1847](#).
- shorthand_def*: [227](#), [1386](#), [1398](#), [1399](#), [1400](#).
- `\show` primitive: [1467](#).
- show_activities*: [236](#), [1469](#).
- show_box*: [198](#), [200](#), [216](#), [236](#), [237](#), [254](#), [666](#), [669](#), [750](#), [837](#), [849](#), [1161](#), [1167](#), [1297](#), [1472](#), [1517](#).
- `\showbox` primitive: [1467](#).
- show_box_breadth*: [254](#), [1517](#).
- `\showboxbreadth` primitive: [256](#).
- show_box_breadth_code*: [254](#), [255](#), [256](#).
- show_box_code*: [1467](#), [1468](#), [1469](#).
- show_box_depth*: [254](#), [1517](#).
- `\showboxdepth` primitive: [256](#).
- show_box_depth_code*: [254](#), [255](#), [256](#).
- show_code*: [1467](#), [1469](#).
- show_context*: [54](#), [78](#), [82](#), [88](#), [332](#), [333](#), [340](#), [556](#), [561](#), [563](#), [1562](#), [1771](#), [1773](#), [1774](#).
- show_cur_cmd_chr*: [321](#), [391](#), [520](#), [524](#), [536](#), [1206](#), [1387](#).
- show_eqtb*: [270](#), [306](#), [1820](#).
- show_groups*: [1672](#), [1673](#), [1674](#).
- `\showgroups` primitive: [1672](#).
- show_ifs*: [1686](#), [1687](#), [1688](#).
- `\showifs` primitive: [1686](#).
- show_info*: [866](#), [867](#).
- show_lists_code*: [1467](#), [1468](#), [1469](#).
- `\showlists` primitive: [1467](#).
- show_node_list*: [191](#), [194](#), [198](#), [199](#), [200](#), [213](#), [216](#), [251](#), [864](#), [866](#), [867](#), [869](#), [1003](#), [1143](#), [1517](#), [1820](#).
- show_sa*: [1820](#), [1836](#), [1837](#), [1838](#).
- show_save_groups*: [1513](#), [1674](#), [1676](#).
- `\showthe` primitive: [1467](#).
- show_the_code*: [1467](#), [1468](#).
- show_token_list*: [194](#), [241](#), [251](#), [286](#), [314](#), [317](#), [328](#), [341](#), [342](#), [426](#), [686](#), [727](#), [1517](#), [1612](#), [1820](#).
- show_tokens*: [1681](#), [1682](#), [1683](#).
- `\showtokens` primitive: [1681](#).
- show_whatever*: [1466](#), [1469](#).
- shown_mode*: [231](#), [233](#), [321](#).
- shrink*: [168](#), [169](#), [182](#), [196](#), [457](#), [488](#), [653](#), [662](#), [705](#), [735](#), [744](#), [830](#), [845](#), [890](#), [983](#), [999](#), [1001](#), [1012](#), [1042](#), [1151](#), [1179](#), [1184](#), [1218](#), [1220](#), [1324](#), [1405](#), [1415](#), [1416](#), [1634](#), [1635](#), [1696](#), [1743](#), [1787](#), [1788](#), [1791](#), [1792](#), [1793](#), [1795](#), [1801](#).
- shrink_amount*: [1634](#).
- shrink_limit*: [705](#).

- shrink_order*: [168](#), [182](#), [196](#), [488](#), [653](#), [662](#), [735](#),
[744](#), [830](#), [845](#), [890](#), [983](#), [999](#), [1000](#), [1151](#), [1179](#),
[1184](#), [1324](#), [1415](#), [1634](#), [1635](#), [1696](#), [1743](#),
[1788](#), [1791](#), [1800](#).
- shrinking*: [153](#), [204](#), [647](#), [657](#), [729](#), [738](#), [838](#), [850](#),
[983](#), [984](#), [985](#), [1324](#), [1634](#), [1696](#), [1720](#).
- si*: [38](#), [42](#), [69](#), [1126](#), [1139](#), [1486](#), [1751](#), [1853](#).
- side*: [821](#).
- sign*: [689](#).
- simple_group*: [291](#), [1239](#), [1244](#), [1658](#), [1676](#).
- Single-character primitives: [289](#).
 - $\backslash-$: [1290](#).
 - $\backslash/$: [287](#).
 - $\backslash_$: [287](#).
- single_base*: [240](#), [284](#), [285](#), [286](#), [376](#), [394](#), [395](#), [400](#),
[468](#), [527](#), [706](#), [1221](#), [1433](#), [1465](#), [1765](#).
- skew_char*: [173](#), [452](#), [575](#), [578](#), [603](#), [705](#), [706](#),
[915](#), [1429](#), [1498](#), [1499](#).
- \backslash skewchar primitive: [1430](#).
- skip*: [242](#), [453](#), [1184](#).
- \backslash skip primitive: [437](#).
- skip_base*: [242](#), [245](#), [247](#), [1400](#), [1413](#).
- skip_blanks*: [325](#), [366](#), [367](#), [369](#), [371](#), [376](#).
- skip_byte*: [571](#), [583](#), [821](#), [915](#), [926](#), [927](#), [1084](#), [1214](#).
- skip_code*: [1234](#), [1235](#), [1236](#).
- \backslash skipdef primitive: [1398](#).
- skip_def_code*: [1398](#), [1399](#), [1400](#).
- skip_line*: [358](#), [519](#), [520](#).
- skipping*: [327](#), [328](#), [358](#), [520](#).
- slant*: [573](#), [584](#), [602](#), [673](#), [1299](#), [1301](#).
- slant_code*: [573](#), [584](#).
- slow_print*: [60](#), [61](#), [63](#), [84](#), [544](#), [562](#), [563](#), [608](#), [670](#),
[1437](#), [1456](#), [1459](#), [1506](#), [1511](#), [1517](#).
- slow_print_substr*: [693](#).
- small_char*: [857](#), [865](#), [871](#), [880](#), [1336](#).
- small_fam*: [857](#), [865](#), [871](#), [880](#), [1336](#).
- small_node_size*: [159](#), [162](#), [163](#), [165](#), [170](#), [171](#), [174](#),
[176](#), [220](#), [224](#), [829](#), [895](#), [1078](#), [1085](#), [1089](#), [1212](#),
[1276](#), [1277](#), [1559](#), [1567](#), [1570](#), [1573](#), [1574](#), [1592](#),
[1593](#), [1594](#), [1595](#), [1596](#), [1601](#), [1602](#), [1621](#), [1622](#),
[1719](#), [1722](#), [1724](#), [1726](#), [1730](#), [1735](#).
- small_number*: [101](#), [102](#), [165](#), [170](#), [172](#), [286](#), [388](#),
[415](#), [439](#), [464](#), [466](#), [476](#), [487](#), [491](#), [496](#), [508](#),
[515](#), [520](#), [523](#), [524](#), [549](#), [604](#), [634](#), [706](#), [729](#),
[772](#), [821](#), [842](#), [862](#), [880](#), [893](#), [894](#), [900](#), [930](#),
[936](#), [1003](#), [1067](#), [1068](#), [1080](#), [1081](#), [1096](#), [1109](#),
[1119](#), [1135](#), [1145](#), [1162](#), [1236](#), [1251](#), [1262](#), [1267](#),
[1352](#), [1357](#), [1367](#), [1374](#), [1387](#), [1412](#), [1422](#), [1423](#),
[1433](#), [1469](#), [1501](#), [1513](#), [1527](#), [1528](#), [1554](#), [1562](#),
[1571](#), [1614](#), [1617](#), [1630](#), [1633](#), [1702](#), [1716](#), [1779](#),
[1812](#), [1816](#), [1818](#), [1820](#), [1822](#), [1839](#).
- snap_glue_ptr*: [695](#), [1571](#), [1600](#), [1601](#), [1602](#), [1634](#).
- snap_node_size*: [695](#), [1571](#), [1601](#), [1602](#).
- snap_unit*: [1634](#).
- snappy_comp_ratio*: [695](#), [1573](#), [1600](#), [1634](#).
- so*: [38](#), [45](#), [59](#), [60](#), [69](#), [286](#), [433](#), [490](#), [545](#), [630](#),
[645](#), [693](#), [940](#), [1106](#), [1128](#), [1130](#), [1131](#), [1134](#),
[1138](#), [1485](#), [1612](#), [1751](#), [1852](#).
- Sorry, I can't find...: [550](#).
- sort_avail*: [149](#), [1487](#).
- sort_dest_names*: [793](#), [802](#).
- sp*: [104](#), [614](#).
- sp*: [484](#).
- sp*: [1634](#).
- space*: [573](#), [584](#), [693](#), [926](#), [929](#), [1218](#).
- space_code*: [573](#), [584](#), [605](#), [1218](#).
- space_factor*: [230](#), [231](#), [444](#), [960](#), [961](#), [973](#), [1205](#),
[1209](#), [1219](#), [1220](#), [1232](#), [1252](#), [1259](#), [1267](#), [1269](#),
[1293](#), [1295](#), [1299](#), [1372](#), [1376](#), [1418](#), [1419](#).
- \backslash spacefactor primitive: [442](#).
- space_shrink*: [573](#), [584](#), [693](#), [1218](#).
- space_shrink_code*: [573](#), [584](#), [605](#).
- space_skip*: [242](#), [1217](#), [1219](#).
- \backslash spaceskip primitive: [244](#).
- space_skip_code*: [242](#), [243](#), [244](#), [1217](#).
- space_stretch*: [573](#), [584](#), [1218](#).
- space_stretch_code*: [573](#), [584](#).
- space_token*: [311](#), [419](#), [490](#), [1391](#), [1758](#).
- spacer*: [225](#), [226](#), [250](#), [311](#), [313](#), [316](#), [320](#), [325](#),
[359](#), [367](#), [369](#), [370](#), [371](#), [376](#), [430](#), [432](#), [433](#),
[469](#), [470](#), [478](#), [490](#), [957](#), [959](#), [965](#), [1110](#), [1136](#),
[1205](#), [1221](#), [1397](#).
- \backslash span primitive: [954](#).
- span_code*: [954](#), [955](#), [956](#), [963](#), [965](#).
- span_count*: [177](#), [203](#), [970](#), [975](#), [982](#).
- span_node_size*: [971](#), [972](#), [977](#).
- spec*: [1548](#), [1550](#), [1554](#), [1563](#).
- spec_code*: [815](#).
- spec_log*: [117](#), [118](#), [120](#).
- \backslash special primitive: [1522](#).
- special_node*: [1519](#), [1522](#), [1524](#), [1526](#), [1532](#), [1600](#),
[1601](#), [1602](#), [1617](#), [1636](#), [1642](#).
- special_out*: [1612](#), [1617](#).
- split*: [1186](#).
- split_bot_mark*: [408](#), [409](#), [1152](#), [1154](#), [1806](#),
[1823](#), [1824](#).
- \backslash splitbotmark primitive: [410](#).
- split_bot_mark_code*: [408](#), [410](#), [411](#), [1513](#), [1806](#),
[1828](#).
- \backslash splitbotmarks primitive: [1806](#).
- split_disc*: [1143](#), [1152](#), [1856](#), [1857](#).
- \backslash splitdiscards primitive: [1858](#).
- split_first_mark*: [408](#), [409](#), [1152](#), [1154](#), [1806](#), [1824](#).
- \backslash splitfirstmark primitive: [410](#).

- split_first_mark_code*: [408](#), [410](#), [411](#), [1806](#).
- \splitfirstmarks* primitive: [1806](#).
- split_fist_mark*: [1823](#).
- split_max_depth*: [158](#), [265](#), [1152](#), [1244](#), [1276](#).
- \splitmaxdepth* primitive: [266](#).
- split_max_depth_code*: [265](#), [266](#).
- split_top_ptr*: [158](#), [206](#), [220](#), [224](#), [1196](#), [1197](#), [1276](#).
- split_top_skip*: [158](#), [242](#), [1143](#), [1152](#), [1187](#), [1189](#), [1196](#), [1276](#).
- \splittopskip* primitive: [244](#).
- split_top_skip_code*: [242](#), [243](#), [244](#), [1144](#).
- split_up*: [1156](#), [1161](#), [1183](#), [1185](#), [1195](#), [1196](#).
- spotless*: [76](#), [77](#), [263](#), [686](#), [1510](#), [1513](#), [1771](#), [1773](#), [1774](#).
- spread*: [815](#).
- sprint_cs*: [241](#), [285](#), [360](#), [421](#), [422](#), [424](#), [498](#), [505](#), [510](#), [587](#), [1470](#).
- sq*: [597](#).
- square roots: [911](#).
- ss_code*: [1234](#), [1235](#), [1236](#).
- ss_glue*: [180](#), [182](#), [889](#), [1236](#).
- st*: [705](#).
- \stbscode* primitive: [1430](#).
- st_bs_code_base*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- stack conventions: [322](#).
- stack_h*: [722](#), [726](#).
- stack_into_box*: [885](#), [887](#).
- stack_level*: [712](#), [717](#), [719](#).
- stack_no*: [727](#).
- stack_size*: [11](#), [323](#), [332](#), [343](#), [1512](#).
- stack_v*: [722](#), [726](#).
- stack_w*: [722](#), [726](#).
- stack_x*: [722](#), [726](#).
- stack_y*: [722](#), [726](#).
- stack_z*: [722](#), [726](#).
- start*: [322](#), [324](#), [325](#), [329](#), [340](#), [341](#), [345](#), [346](#), [347](#), [348](#), [350](#), [351](#), [353](#), [382](#), [384](#), [385](#), [393](#), [394](#), [509](#), [564](#), [1752](#).
- start_cs*: [363](#), [376](#), [377](#).
- start_eq_no*: [1316](#), [1318](#).
- start_field*: [322](#), [324](#).
- start_font_error_message*: [587](#), [593](#).
- start_here*: [5](#), [1510](#).
- start_input*: [388](#), [402](#), [404](#), [563](#), [1515](#).
- start_of_TEX*: [6](#), [1510](#).
- start_packet*: [725](#).
- start_par*: [226](#), [1264](#), [1265](#), [1266](#), [1268](#).
- start_status*: [727](#).
- stat*: [7](#), [135](#), [138](#), [139](#), [140](#), [141](#), [143](#), [148](#), [270](#), [279](#), [296](#), [299](#), [304](#), [305](#), [306](#), [667](#), [1000](#), [1003](#), [1019](#), [1029](#), [1037](#), [1162](#), [1180](#), [1185](#), [1511](#), [1659](#), [1820](#), [1836](#), [1837](#), [1838](#).
- state*: [87](#), [322](#), [324](#), [325](#), [329](#), [333](#), [334](#), [345](#), [347](#), [350](#), [352](#), [353](#), [359](#), [363](#), [365](#), [366](#), [368](#), [369](#), [371](#), [374](#), [375](#), [376](#), [416](#), [509](#), [563](#), [1513](#).
- state_field*: [322](#), [324](#), [1307](#), [1772](#).
- step*: [705](#).
- stomach*: [428](#).
- stop*: [225](#), [1221](#), [1222](#), [1228](#), [1229](#), [1230](#), [1270](#).
- stop_flag*: [571](#), [583](#), [821](#), [915](#), [926](#), [927](#), [1084](#), [1214](#).
- store_background*: [1038](#).
- store_break_width*: [1017](#).
- store_fmt_file*: [1478](#), [1513](#).
- store_four_quarters*: [590](#), [594](#), [595](#), [600](#), [601](#).
- store_new_token*: [397](#), [398](#), [419](#), [423](#), [425](#), [433](#), [490](#), [492](#), [499](#), [500](#), [502](#), [503](#), [508](#), [509](#), [1680](#), [1758](#), [1764](#).
- store_scaled*: [597](#), [598](#), [600](#), [602](#).
- store_scaled_f*: [597](#), [712](#), [717](#), [725](#).
- storepacket*: [706](#), [718](#).
- str_eq_buf*: [45](#), [278](#).
- str_eq_str*: [46](#), [281](#), [693](#), [705](#), [799](#), [1436](#).
- str_in_str*: [686](#), [693](#).
- str_less_str*: [793](#).
- str_number*: [38](#), [39](#), [43](#), [45](#), [46](#), [47](#), [62](#), [63](#), [79](#), [93](#), [94](#), [95](#), [195](#), [196](#), [281](#), [286](#), [306](#), [433](#), [496](#), [538](#), [545](#), [551](#), [553](#), [555](#), [556](#), [558](#), [575](#), [586](#), [686](#), [693](#), [698](#), [702](#), [704](#), [705](#), [706](#), [708](#), [712](#), [725](#), [727](#), [749](#), [772](#), [793](#), [805](#), [809](#), [1101](#), [1104](#), [1109](#), [1433](#), [1455](#), [1475](#), [1535](#), [1550](#), [1553](#), [1562](#), [1585](#), [1599](#), [1624](#), [1627](#), [1676](#), [1750](#), [1811](#), [1820](#).
- str_pool*: [38](#), [39](#), [42](#), [43](#), [45](#), [46](#), [47](#), [59](#), [60](#), [69](#), [70](#), [274](#), [279](#), [283](#), [286](#), [325](#), [433](#), [490](#), [545](#), [629](#), [630](#), [645](#), [666](#), [686](#), [693](#), [702](#), [706](#), [727](#), [749](#), [750](#), [793](#), [938](#), [940](#), [1104](#), [1106](#), [1109](#), [1116](#), [1485](#), [1486](#), [1512](#), [1535](#), [1585](#), [1612](#), [1627](#), [1750](#), [1751](#).
- str_ptr*: [38](#), [39](#), [41](#), [43](#), [44](#), [47](#), [59](#), [60](#), [70](#), [279](#), [281](#), [284](#), [496](#), [543](#), [551](#), [563](#), [645](#), [673](#), [693](#), [727](#), [1436](#), [1485](#), [1486](#), [1499](#), [1501](#), [1505](#), [1510](#), [1512](#), [1612](#).
- str_room*: [42](#), [198](#), [279](#), [490](#), [542](#), [551](#), [706](#), [712](#), [717](#), [726](#), [727](#), [1114](#), [1433](#), [1455](#), [1506](#), [1511](#), [1612](#), [1750](#).
- str_start*: [38](#), [39](#), [40](#), [41](#), [43](#), [44](#), [45](#), [46](#), [47](#), [59](#), [60](#), [69](#), [70](#), [274](#), [279](#), [281](#), [286](#), [433](#), [496](#), [497](#), [543](#), [545](#), [630](#), [645](#), [686](#), [693](#), [702](#), [706](#), [727](#), [749](#), [793](#), [939](#), [1104](#), [1106](#), [1109](#), [1116](#), [1485](#), [1486](#), [1535](#), [1585](#), [1612](#), [1627](#), [1751](#).
- str_toks*: [490](#), [491](#), [496](#), [497](#), [1685](#).
- stretch*: [168](#), [169](#), [182](#), [196](#), [457](#), [488](#), [653](#), [662](#), [705](#), [735](#), [744](#), [830](#), [845](#), [890](#), [983](#), [1001](#), [1012](#), [1042](#), [1151](#), [1179](#), [1184](#), [1218](#), [1220](#), [1324](#), [1405](#), [1415](#), [1416](#), [1634](#), [1635](#), [1696](#), [1743](#), [1787](#), [1788](#), [1791](#), [1792](#), [1793](#), [1795](#), [1801](#), [1840](#), [1850](#).

- stretch_amount*: [1634](#).
stretch_limit: [705](#).
stretch_order: [168](#), [182](#), [196](#), [488](#), [653](#), [662](#), [735](#),
[744](#), [830](#), [845](#), [890](#), [983](#), [1001](#), [1012](#), [1042](#), [1151](#),
[1179](#), [1184](#), [1324](#), [1415](#), [1634](#), [1635](#), [1696](#), [1743](#),
[1788](#), [1791](#), [1800](#), [1840](#).
stretching: [153](#), [653](#), [662](#), [735](#), [744](#), [832](#), [847](#), [983](#),
[984](#), [985](#), [1324](#), [1635](#), [1696](#).
string pool: [47](#), [1484](#).
\string primitive: [494](#).
string_code: [494](#), [495](#), [497](#), [498](#).
string_vacancies: [11](#), [52](#).
style: [900](#), [901](#), [934](#), [935](#), [936](#).
style_node: [178](#), [862](#), [864](#), [872](#), [904](#), [905](#), [935](#),
[1345](#), [1716](#).
style_node_size: [862](#), [863](#), [872](#), [937](#), [1716](#).
sub_box: [855](#), [861](#), [866](#), [872](#), [894](#), [908](#), [909](#), [911](#),
[912](#), [923](#), [928](#), [1252](#), [1269](#), [1344](#).
sub_char_shrink: [1013](#), [1015](#).
sub_char_shrink_end: [1013](#).
sub_char_stretch: [1013](#), [1015](#).
sub_char_stretch_end: [1013](#).
sub_disc_width_from_active_width: [1013](#), [1043](#).
sub_drop: [874](#), [930](#).
sub_kern_shrink: [1013](#), [1015](#).
sub_kern_shrink_end: [1013](#).
sub_kern_stretch: [1013](#), [1015](#).
sub_kern_stretch_end: [1013](#).
sub_mark: [225](#), [316](#), [320](#), [369](#), [1222](#), [1351](#).
sub_mlist: [855](#), [857](#), [866](#), [894](#), [916](#), [928](#), [1357](#),
[1361](#), [1362](#), [1367](#).
sub_style: [876](#), [924](#), [931](#), [933](#).
sub_sup: [1351](#), [1352](#).
subscr: [855](#), [857](#), [860](#), [861](#), [864](#), [870](#), [872](#), [912](#), [916](#),
[923](#), [924](#), [925](#), [926](#), [927](#), [928](#), [929](#), [930](#), [931](#), [933](#),
[1327](#), [1339](#), [1341](#), [1351](#), [1352](#), [1353](#), [1362](#).
subscripts: [928](#), [1351](#).
subst_ex_font: [821](#), [823](#), [826](#).
subst_font_type: [703](#).
substituted: [821](#).
substr_of_str: [749](#), [769](#), [805](#).
subtype: [151](#), [152](#), [153](#), [154](#), [157](#), [158](#), [160](#), [161](#),
[162](#), [163](#), [164](#), [165](#), [167](#), [168](#), [170](#), [171](#), [172](#), [173](#),
[174](#), [176](#), [177](#), [193](#), [201](#), [206](#), [207](#), [208](#), [209](#), [210](#),
[211](#), [450](#), [498](#), [515](#), [521](#), [522](#), [643](#), [653](#), [655](#), [662](#),
[664](#), [674](#), [695](#), [705](#), [735](#), [744](#), [772](#), [821](#), [823](#), [830](#),
[842](#), [845](#), [855](#), [856](#), [860](#), [861](#), [862](#), [863](#), [864](#),
[870](#), [891](#), [904](#), [905](#), [906](#), [907](#), [923](#), [937](#), [940](#),
[942](#), [960](#), [967](#), [969](#), [983](#), [993](#), [994](#), [996](#), [1003](#),
[1011](#), [1015](#), [1016](#), [1017](#), [1018](#), [1040](#), [1042](#), [1044](#),
[1045](#), [1053](#), [1055](#), [1071](#), [1072](#), [1073](#), [1074](#), [1078](#),
[1085](#), [1143](#), [1156](#), [1161](#), [1163](#), [1175](#), [1183](#), [1184](#),
[1193](#), [1195](#), [1196](#), [1210](#), [1236](#), [1237](#), [1254](#), [1256](#),
[1276](#), [1277](#), [1289](#), [1301](#), [1324](#), [1335](#), [1339](#), [1341](#),
[1347](#), [1357](#), [1367](#), [1513](#), [1519](#), [1527](#), [1571](#), [1600](#),
[1601](#), [1602](#), [1603](#), [1604](#), [1605](#), [1606](#), [1607](#), [1608](#),
[1609](#), [1617](#), [1619](#), [1632](#), [1634](#), [1636](#), [1642](#), [1688](#),
[1696](#), [1708](#), [1714](#), [1716](#), [1717](#), [1725](#), [1733](#), [1734](#),
[1736](#), [1774](#), [1785](#), [1786](#), [1812](#).
sub1: [874](#), [931](#).
sub2: [874](#), [933](#).
succumb: [93](#), [94](#), [95](#), [686](#), [1480](#).
sup_dest_names_size: [695](#), [698](#), [1511](#).
sup_drop: [874](#), [930](#).
sup_mark: [225](#), [316](#), [320](#), [366](#), [377](#), [1222](#), [1351](#),
[1352](#), [1353](#).
sup_obj_tab_size: [695](#), [698](#), [1511](#).
sup_pdf_mem_size: [675](#), [678](#), [1511](#).
sup_pdf_os_buf_size: [679](#), [686](#).
sup_pk_dpi: [695](#).
sup_style: [876](#), [924](#), [932](#).
superscripts: [928](#), [1351](#).
supscr: [855](#), [857](#), [860](#), [861](#), [864](#), [870](#), [872](#), [912](#),
[916](#), [924](#), [925](#), [926](#), [927](#), [928](#), [930](#), [932](#), [1327](#),
[1339](#), [1341](#), [1351](#), [1352](#), [1353](#), [1362](#).
sup1: [874](#), [932](#).
sup2: [874](#), [932](#).
sup3: [874](#), [932](#).
sw: [586](#), [597](#), [602](#).
switch: [363](#), [365](#), [366](#), [368](#), [372](#).
synch_h: [643](#), [648](#), [652](#), [656](#), [661](#), [665](#), [1612](#).
synch_v: [643](#), [648](#), [652](#), [656](#), [660](#), [661](#), [665](#), [1612](#).
sys_day: [259](#), [264](#), [562](#).
sys_month: [259](#), [264](#), [562](#).
sys_obj_ptr: [696](#), [697](#), [698](#), [800](#), [810](#), [812](#), [813](#),
[1502](#), [1503](#).
sys_time: [259](#), [264](#), [562](#).
sys_year: [259](#), [264](#), [562](#).
system dependencies: [2](#), [3](#), [4](#), [9](#), [10](#), [11](#), [12](#), [19](#), [21](#),
[23](#), [26](#), [27](#), [28](#), [32](#), [33](#), [34](#), [35](#), [37](#), [38](#), [49](#), [56](#), [59](#),
[61](#), [72](#), [81](#), [84](#), [96](#), [109](#), [112](#), [128](#), [130](#), [131](#), [179](#),
[204](#), [259](#), [326](#), [335](#), [350](#), [511](#), [537](#), [538](#), [539](#), [540](#),
[541](#), [542](#), [543](#), [544](#), [545](#), [546](#), [547](#), [549](#), [551](#), [563](#),
[564](#), [583](#), [590](#), [618](#), [622](#), [624](#), [972](#), [1482](#), [1509](#),
[1510](#), [1511](#), [1516](#), [1518](#), [1828](#), [1864](#).
sz: [1750](#), [1751](#), [1753](#).
s1: [82](#), [88](#), [793](#), [1535](#), [1562](#), [1585](#).
s2: [82](#), [88](#), [793](#), [1535](#), [1562](#), [1585](#).
s3: [82](#), [88](#).
s4: [82](#), [88](#).
t: [46](#), [107](#), [108](#), [143](#), [236](#), [299](#), [301](#), [302](#), [303](#), [345](#),
[363](#), [388](#), [415](#), [490](#), [496](#), [499](#), [689](#), [706](#), [878](#),
[879](#), [900](#), [930](#), [974](#), [1003](#), [1004](#), [1051](#), [1081](#),
[1109](#), [1141](#), [1145](#), [1205](#), [1299](#), [1352](#), [1367](#),

- [1374](#), [1433](#), [1464](#), [1469](#), [1720](#), [1730](#), [1735](#), [1741](#),
[1779](#), [1796](#), [1816](#), [1820](#).
- t_open_in*: [33](#), [37](#).
- t_open_out*: [33](#), [1510](#).
- tab_mark*: [225](#), [311](#), [316](#), [364](#), [369](#), [954](#), [955](#), [956](#),
[957](#), [958](#), [962](#), [1302](#).
- tab_skip*: [242](#).
- \tabskip* primitive: [244](#).
- tab_skip_code*: [242](#), [243](#), [244](#), [952](#), [956](#), [960](#),
[967](#), [969](#), [983](#).
- tab_token*: [311](#), [1304](#).
- tag*: [569](#), [570](#), [580](#).
- tag_code*: [173](#), [452](#), [1429](#), [1430](#), [1431](#).
- \tagcode* primitive: [1430](#).
- tail*: [160](#), [230](#), [231](#), [232](#), [233](#), [234](#), [450](#), [853](#), [892](#),
[950](#), [960](#), [969](#), [970](#), [973](#), [986](#), [990](#), [1065](#), [1170](#),
[1192](#), [1198](#), [1201](#), [1209](#), [1210](#), [1211](#), [1212](#), [1215](#),
[1216](#), [1217](#), [1219](#), [1230](#), [1236](#), [1237](#), [1252](#), [1254](#),
[1256](#), [1267](#), [1272](#), [1276](#), [1277](#), [1281](#), [1286](#), [1289](#),
[1293](#), [1295](#), [1296](#), [1299](#), [1301](#), [1321](#), [1326](#), [1331](#),
[1334](#), [1335](#), [1339](#), [1341](#), [1344](#), [1347](#), [1350](#), [1352](#),
[1353](#), [1357](#), [1360](#), [1362](#), [1363](#), [1367](#), [1372](#), [1381](#),
[1382](#), [1527](#), [1528](#), [1529](#), [1530](#), [1531](#), [1532](#), [1536](#),
[1537](#), [1538](#), [1544](#), [1547](#), [1552](#), [1554](#), [1556](#), [1558](#),
[1563](#), [1564](#), [1573](#), [1620](#), [1621](#), [1622](#), [1860](#).
- tail_append*: [232](#), [960](#), [969](#), [990](#), [1210](#), [1212](#), [1215](#),
[1216](#), [1230](#), [1232](#), [1236](#), [1237](#), [1267](#), [1269](#),
[1276](#), [1279](#), [1288](#), [1289](#), [1293](#), [1326](#), [1334](#), [1339](#),
[1341](#), [1344](#), [1347](#), [1348](#), [1353](#), [1367](#), [1372](#), [1379](#),
[1381](#), [1382](#), [1572](#), [1700](#).
- tail_field*: [230](#), [231](#), [1170](#).
- tail_page_disc*: [1174](#), [1856](#).
- take_frac*: [114](#), [126](#), [127](#).
- take_fraction*: [1796](#).
- tally*: [54](#), [55](#), [57](#), [58](#), [314](#), [334](#), [337](#), [338](#), [339](#).
- tats**: [7](#).
- temp_head*: [180](#), [328](#), [417](#), [422](#), [426](#), [490](#), [492](#), [493](#),
[496](#), [497](#), [504](#), [893](#), [894](#), [928](#), [934](#), [990](#), [1036](#),
[1037](#), [1038](#), [1051](#), [1053](#), [1054](#), [1055](#), [1061](#), [1143](#),
[1240](#), [1241](#), [1370](#), [1372](#), [1375](#), [1473](#), [1680](#), [1685](#),
[1704](#), [1706](#), [1731](#), [1732](#), [1734](#), [1735](#), [1750](#).
- temp_ptr*: [133](#), [172](#), [646](#), [647](#), [651](#), [656](#), [657](#), [660](#),
[665](#), [668](#), [729](#), [733](#), [737](#), [738](#), [742](#), [746](#), [752](#),
[853](#), [866](#), [867](#), [1144](#), [1176](#), [1196](#), [1212](#), [1217](#),
[1513](#), [1702](#), [1704](#), [1706](#), [1709](#), [1718](#), [1719](#),
[1720](#), [1724](#), [1743](#).
- ten_pow*: [687](#), [688](#), [689](#), [690](#), [792](#), [1634](#).
- term_and_log*: [54](#), [57](#), [58](#), [71](#), [75](#), [92](#), [263](#), [560](#),
[1474](#), [1506](#), [1513](#), [1614](#).
- term_in*: [32](#), [33](#), [34](#), [36](#), [37](#), [71](#), [1516](#), [1517](#).
- term_input*: [71](#), [78](#).
- term_offset*: [54](#), [55](#), [57](#), [58](#), [61](#), [62](#), [71](#), [563](#), [666](#),
[750](#), [1456](#), [1752](#).
- term_only*: [54](#), [55](#), [57](#), [58](#), [71](#), [75](#), [92](#), [561](#), [1474](#),
[1511](#), [1513](#).
- term_out*: [32](#), [33](#), [34](#), [35](#), [36](#), [37](#), [51](#), [56](#).
- terminal_input*: [326](#), [335](#), [350](#), [352](#), [382](#).
- test_char*: [1081](#), [1084](#).
- test_no_ligatures*: [452](#), [604](#).
- TEX*: [2](#), [4](#).
- TeX capacity exceeded ...**: [94](#).
 - buffer size: [35](#), [286](#), [350](#), [400](#), [1765](#).
 - exception dictionary: [1115](#).
 - font memory: [607](#).
 - grouping levels: [296](#).
 - hash size: [279](#).
 - input stack size: [343](#).
 - main memory size: [138](#), [143](#).
 - number of strings: [43](#), [543](#).
 - parameter stack size: [416](#).
 - pattern memory: [1129](#), [1139](#).
 - pool size: [42](#).
 - primitive size: [282](#).
 - save size: [295](#).
 - semantic nest size: [234](#).
 - text input levels: [350](#).
- TEX.POOL check sum...**: [53](#).
- TEX.POOL doesn't match**: [53](#).
- TEX.POOL has no check sum**: [52](#).
- TEX.POOL line doesn't...**: [52](#).
- TEX_area*: [540](#), [563](#).
- tex_b_openin*: [772](#).
- TeX_banner*: [2](#).
- TEX_font_area*: [540](#), [589](#).
- TEX_format_default*: [546](#), [547](#), [549](#).
- tex_int_pars*: [254](#).
- tex_toks*: [248](#).
- The T_EXbook*: [1](#), [23](#), [49](#), [108](#), [225](#), [441](#), [472](#), [482](#),
[485](#), [857](#), [862](#), [938](#), [1391](#), [1509](#).
- TeXfonts**: [540](#).
- TeXformats**: [11](#), [547](#).
- TeXinputs**: [540](#).
- texput**: [35](#), [560](#), [1433](#).
- text*: [274](#), [276](#), [277](#), [278](#), [279](#), [284](#), [285](#), [286](#), [287](#),
[394](#), [395](#), [517](#), [527](#), [579](#), [706](#), [954](#), [1221](#), [1364](#),
[1392](#), [1433](#), [1494](#), [1613](#).
- Text line contains...**: [368](#).
- text_char*: [19](#), [20](#), [25](#), [47](#).
- \textfont* primitive: [1406](#).
- text_mlist*: [863](#), [869](#), [872](#), [905](#), [1350](#).
- text_size*: [873](#), [877](#), [906](#), [1371](#), [1375](#).
- text_style*: [862](#), [868](#), [877](#), [905](#), [911](#), [918](#), [919](#), [920](#),
[922](#), [923](#), [932](#), [1345](#), [1370](#), [1372](#).
- \textstyle* primitive: [1345](#).

- TeXXeT*: 1697.
- TeXXeT_code*: 2, 1697, 1698.
- TeXXeT_en*: 821, 823, 1053, 1054, 1055, 1697, 1700, 1731, 1732, 1733.
- TeXXeT_state*: 1697.
- \TeXXeT_state* primitive: 1698.
- TeX82*: 1, 99.
- TFM files: 565.
- tfm_file*: 565, 586, 589, 590, 602.
- tfm_lookup*: 705, 706, 712.
- tfm_width*: 712, 717.
- TFtoPL: 587.
- That makes 100 errors...: 82.
- the*: 228, 287, 288, 388, 391, 504, 1683.
- The following...deleted: 669, 1167, 1297.
- \the* primitive: 287.
- the_toks*: 491, 492, 493, 504, 1473, 1685.
- thick_mu_skip*: 242.
- \thickmuskip* primitive: 244.
- thick_mu_skip_code*: 242, 243, 244, 940.
- thickness*: 857, 871, 899, 917, 918, 920, 921, 1358.
- thin_mu_skip*: 242.
- \thinmuskip* primitive: 244.
- thin_mu_skip_code*: 242, 243, 244, 247, 940.
- This can't happen: 95.
- /:* 112.
- align*: 974.
- copying*: 224.
- curlevel*: 303.
- disc1*: 1015.
- disc2*: 1016.
- disc3*: 1044.
- disc4*: 1045.
- display*: 1376.
- endv*: 965.
- ext1*: 1526.
- ext2*: 1601.
- ext3*: 1602.
- ext4*: 1617.
- flushing*: 220.
- if*: 523.
- line breaking: 1051.
- LR1: 1709.
- LR2: 1722.
- LR3: 1727.
- mlist1*: 902.
- mlist2*: 928.
- mlist3*: 935.
- mlist4*: 940.
- page: 1175.
- paragraph: 1040.
- pdfvlistout: 740.
- prefix: 1387.
- pruning: 1143.
- right: 1361.
- rightbrace: 1244.
- tail1: 1256.
- vcenter: 910.
- vertbreak: 1148.
- vlistout: 658.
- vpack: 843.
- 256 spans: 972.
- this_box*: 647, 652, 653, 657, 661, 662, 729, 730, 734, 735, 738, 739, 743, 744, 1634, 1635, 1636, 1642, 1711, 1712, 1718, 1719, 1720.
- this_if*: 524, 527, 529, 531, 532, 1766.
- thread*: 1597.
- thread_title*: 1597.
- threads*: 790, 804, 1511.
- three_codes*: 815.
- threshold*: 1002, 1025, 1028, 1037.
- Tight *\hbox*...: 841.
- Tight *\vbox*...: 852.
- tight_fit*: 991, 993, 1004, 1007, 1008, 1010, 1027, 1839, 1845.
- time*: 254, 259, 645, 792.
- \time* primitive: 256.
- time_code*: 254, 255, 256.
- tini**: 8.
- tmp_b0*: 706, 710, 712, 714.
- tmp_b1*: 706, 710, 712, 714.
- tmp_b2*: 706, 710, 714.
- tmp_b3*: 706, 710, 714.
- tmp_int*: 710, 726.
- tmp_k1*: 1205, 1209, 1214, 1215.
- tmp_k2*: 1205, 1210.
- tmp_v*: 1634.
- tmp_w*: 705, 710.
- to*: 815, 1258, 1401.
- tok_val*: 436, 441, 444, 454, 491, 1400, 1402, 1403, 1487, 1488, 1812, 1815, 1820.
- tok_val_limit*: 1812, 1834.
- token: 311.
- token_list*: 329, 333, 334, 345, 347, 352, 359, 363, 368, 416, 1307, 1513, 1772.
- token_ref_count*: 218, 221, 313, 499, 508, 1154, 1680.
- token_show*: 317, 318, 345, 427, 1455, 1460, 1473, 1614, 1685, 1750.
- token_type*: 329, 333, 334, 336, 341, 345, 346, 347, 349, 405, 416, 1201, 1271.
- tokens_to_string*: 497, 686, 708, 727, 769, 772, 792, 805, 1535, 1550, 1553, 1561, 1563, 1585, 1587, 1627, 1634.

- toks*: [248](#).
- `\toks` primitive: [287](#).
- toks_base*: [248](#), [249](#), [250](#), [251](#), [329](#), [441](#), [1400](#), [1402](#), [1403](#).
- `\toksdef` primitive: [1398](#).
- toks_def_code*: [1398](#), [1400](#).
- toks_register*: [227](#), [287](#), [288](#), [439](#), [441](#), [1386](#), [1397](#), [1400](#), [1402](#), [1403](#), [1820](#), [1830](#), [1831](#).
- tolerance*: [254](#), [258](#), [1002](#), [1037](#).
- `\tolerance` primitive: [256](#).
- tolerance_code*: [254](#), [255](#), [256](#).
- Too many }'s: [1244](#).
- Too many color stacks: [497](#).
- too_big*: [1796](#).
- too_small*: [1479](#), [1482](#).
- top*: [572](#), [693](#).
- top_bot_mark*: [228](#), [318](#), [388](#), [391](#), [410](#), [411](#), [412](#), [1806](#).
- top_edge*: [657](#), [664](#), [738](#), [739](#), [1636](#).
- top_mark*: [408](#), [409](#), [1187](#), [1806](#), [1825](#).
- `\topmark` primitive: [410](#).
- top_mark_code*: [408](#), [410](#), [412](#), [1513](#), [1806](#), [1828](#).
- `\topmarks` primitive: [1806](#).
- top_skip*: [242](#).
- `\topskip` primitive: [244](#).
- top_skip_code*: [242](#), [243](#), [244](#), [1176](#).
- total_demerits*: [993](#), [1019](#), [1020](#), [1029](#), [1038](#), [1048](#), [1049](#).
- total_font_shrink*: [997](#), [1025](#).
- total_font_stretch*: [997](#), [1025](#).
- total_height*: [1161](#).
- total_mathex_params*: [875](#), [1371](#).
- total_mathsy_params*: [874](#), [1371](#).
- total_pages*: [619](#), [620](#), [645](#), [668](#), [670](#), [751](#), [752](#), [770](#), [794](#).
- total_pw*: [1003](#), [1025](#).
- total_shrink*: [816](#), [822](#), [830](#), [838](#), [839](#), [840](#), [841](#), [845](#), [850](#), [851](#), [852](#), [970](#), [1377](#).
- total_stretch*: [816](#), [822](#), [830](#), [832](#), [833](#), [834](#), [845](#), [847](#), [848](#), [970](#).
- Trabb Pardo, Luis Isidoro: [2](#).
- tracing_assigns*: [254](#), [299](#), [1836](#), [1837](#).
- `\tracingassigns` primitive: [1654](#).
- tracing_assigns_code*: [254](#), [1654](#), [1656](#).
- tracing_commands*: [254](#), [391](#), [524](#), [535](#), [536](#), [1206](#), [1387](#).
- `\tracingcommands` primitive: [256](#).
- tracing_commands_code*: [254](#), [255](#), [256](#).
- tracing_groups*: [254](#), [296](#), [304](#).
- `\tracinggroups` primitive: [1654](#).
- tracing_groups_code*: [254](#), [1654](#), [1656](#).
- tracing_ifs*: [254](#), [321](#), [520](#), [524](#), [536](#).
- `\tracingifs` primitive: [1654](#).
- tracing_ifs_code*: [254](#), [1654](#), [1656](#).
- tracing_lost_chars*: [254](#), [608](#).
- `\tracinglostchars` primitive: [256](#).
- tracing_lost_chars_code*: [254](#), [255](#), [256](#).
- tracing_macros*: [254](#), [345](#), [415](#), [426](#).
- `\tracingmacros` primitive: [256](#).
- tracing_macros_code*: [254](#), [255](#), [256](#).
- tracing_nesting*: [254](#), [384](#), [1771](#), [1772](#), [1773](#), [1774](#).
- `\tracingnesting` primitive: [1654](#).
- tracing_nesting_code*: [254](#), [1654](#), [1656](#).
- tracing_online*: [254](#), [263](#), [608](#), [1469](#), [1474](#).
- `\tracingonline` primitive: [256](#).
- tracing_online_code*: [254](#), [255](#), [256](#).
- tracing_output*: [254](#), [666](#), [669](#), [750](#).
- `\tracingoutput` primitive: [256](#).
- tracing_output_code*: [254](#), [255](#), [256](#).
- tracing_pages*: [254](#), [1162](#), [1180](#), [1185](#).
- `\tracingpages` primitive: [256](#).
- tracing_pages_code*: [254](#), [255](#), [256](#).
- tracing_paragraphs*: [254](#), [1000](#), [1019](#), [1029](#), [1037](#).
- `\tracingparagraphs` primitive: [256](#).
- tracing_paragraphs_code*: [254](#), [255](#), [256](#).
- tracing_restores*: [254](#), [305](#), [1838](#).
- `\tracingrestores` primitive: [256](#).
- tracing_restores_code*: [254](#), [255](#), [256](#).
- tracing_scan_tokens*: [254](#), [1752](#).
- `\tracingscantokens` primitive: [1654](#).
- tracing_scan_tokens_code*: [254](#), [1654](#), [1656](#).
- tracing_stats*: [135](#), [254](#), [667](#), [1504](#), [1511](#).
- `\tracingstats` primitive: [256](#).
- tracing_stats_code*: [254](#), [255](#), [256](#).
- Transcript written...: [1511](#).
- trap_zero_glue*: [1404](#), [1405](#), [1412](#).
- trapped_given*: [805](#).
- trick_buf*: [54](#), [58](#), [337](#), [339](#).
- trick_count*: [54](#), [58](#), [337](#), [338](#), [339](#).
- Trickey, Howard Wellington: [2](#).
- trie*: [1095](#), [1096](#), [1097](#), [1125](#), [1127](#), [1128](#), [1129](#), [1133](#), [1134](#), [1141](#), [1500](#), [1501](#).
- trie_back*: [1125](#), [1129](#), [1131](#).
- trie_c*: [1122](#), [1123](#), [1126](#), [1128](#), [1130](#), [1131](#), [1134](#), [1138](#), [1139](#), [1852](#), [1853](#).
- trie_char*: [1095](#), [1096](#), [1098](#), [1133](#), [1134](#), [1855](#).
- trie_fix*: [1133](#), [1134](#).
- trie_hash*: [1122](#), [1123](#), [1124](#), [1125](#), [1127](#).
- trie_l*: [1122](#), [1123](#), [1124](#), [1132](#), [1134](#), [1135](#), [1138](#), [1139](#), [1853](#).
- trie_link*: [1095](#), [1096](#), [1098](#), [1125](#), [1127](#), [1128](#), [1129](#), [1130](#), [1131](#), [1133](#), [1134](#), [1855](#).
- trie_max*: [1125](#), [1127](#), [1129](#), [1133](#), [1500](#), [1501](#).
- trie_min*: [1125](#), [1127](#), [1128](#), [1131](#), [1854](#).

- trie_node*: [1123](#), [1124](#).
trie_not_ready: [1066](#), [1109](#), [1125](#), [1126](#), [1135](#),
[1141](#), [1500](#), [1501](#).
trie_o: [1122](#), [1123](#), [1134](#), [1138](#), [1139](#), [1853](#).
trie_op: [1095](#), [1096](#), [1098](#), [1099](#), [1118](#), [1133](#),
[1134](#), [1851](#), [1855](#).
trie_op_hash: [1118](#), [1119](#), [1120](#), [1121](#), [1123](#), [1127](#).
trie_op_lang: [1118](#), [1119](#), [1120](#), [1127](#).
trie_op_ptr: [1118](#), [1119](#), [1120](#), [1121](#), [1500](#), [1501](#).
trie_op_size: [11](#), [1096](#), [1118](#), [1119](#), [1121](#), [1500](#),
[1501](#).
trie_op_val: [1118](#), [1119](#), [1120](#), [1127](#).
trie_pack: [1132](#), [1141](#), [1854](#).
trie_pointer: [1095](#), [1096](#), [1097](#), [1122](#), [1123](#), [1124](#),
[1125](#), [1128](#), [1132](#), [1134](#), [1135](#), [1141](#), [1855](#).
trie_ptr: [1122](#), [1126](#), [1127](#), [1139](#).
trie_r: [1122](#), [1123](#), [1124](#), [1130](#), [1131](#), [1132](#), [1134](#),
[1138](#), [1139](#), [1851](#), [1852](#), [1853](#).
trie_ref: [1125](#), [1127](#), [1128](#), [1131](#), [1132](#), [1134](#), [1854](#).
trie_root: [1122](#), [1124](#), [1126](#), [1127](#), [1133](#), [1141](#),
[1851](#), [1854](#).
trie_size: [11](#), [1095](#), [1123](#), [1125](#), [1127](#), [1129](#),
[1139](#), [1501](#).
trie_taken: [1125](#), [1127](#), [1128](#), [1129](#), [1131](#).
trie_used: [1118](#), [1119](#), [1120](#), [1121](#), [1500](#), [1501](#).
true: [4](#), [16](#), [31](#), [34](#), [37](#), [45](#), [46](#), [49](#), [51](#), [53](#), [71](#), [77](#),
[88](#), [97](#), [98](#), [104](#), [105](#), [106](#), [107](#), [112](#), [114](#), [115](#),
[186](#), [187](#), [274](#), [276](#), [278](#), [304](#), [333](#), [349](#), [350](#), [358](#),
[368](#), [383](#), [384](#), [387](#), [398](#), [400](#), [404](#), [433](#), [439](#),
[456](#), [466](#), [470](#), [473](#), [479](#), [487](#), [488](#), [512](#), [527](#),
[534](#), [538](#), [542](#), [550](#), [552](#), [560](#), [589](#), [605](#), [619](#),
[649](#), [656](#), [665](#), [666](#), [669](#), [683](#), [685](#), [686](#), [689](#),
[692](#), [693](#), [698](#), [699](#), [702](#), [705](#), [706](#), [720](#), [726](#),
[727](#), [737](#), [746](#), [747](#), [748](#), [749](#), [750](#), [766](#), [791](#),
[793](#), [794](#), [800](#), [802](#), [821](#), [837](#), [849](#), [880](#), [893](#),
[965](#), [1000](#), [1001](#), [1002](#), [1003](#), [1025](#), [1028](#), [1037](#),
[1054](#), [1055](#), [1056](#), [1058](#), [1078](#), [1080](#), [1085](#), [1086](#),
[1126](#), [1131](#), [1137](#), [1138](#), [1167](#), [1195](#), [1196](#), [1200](#),
[1205](#), [1210](#), [1212](#), [1216](#), [1227](#), [1230](#), [1256](#), [1259](#),
[1266](#), [1277](#), [1297](#), [1321](#), [1339](#), [1370](#), [1371](#), [1394](#),
[1400](#), [1402](#), [1412](#), [1413](#), [1429](#), [1434](#), [1446](#), [1455](#),
[1459](#), [1474](#), [1479](#), [1514](#), [1520](#), [1532](#), [1535](#), [1536](#),
[1537](#), [1538](#), [1539](#), [1540](#), [1542](#), [1544](#), [1546](#), [1547](#),
[1549](#), [1550](#), [1551](#), [1552](#), [1553](#), [1556](#), [1558](#), [1559](#),
[1561](#), [1563](#), [1565](#), [1566](#), [1567](#), [1570](#), [1572](#), [1573](#),
[1578](#), [1586](#), [1587](#), [1588](#), [1589](#), [1591](#), [1592](#), [1593](#),
[1594](#), [1595](#), [1596](#), [1615](#), [1619](#), [1626](#), [1632](#), [1636](#),
[1642](#), [1645](#), [1653](#), [1659](#), [1676](#), [1753](#), [1764](#), [1765](#),
[1771](#), [1772](#), [1774](#), [1787](#), [1790](#), [1794](#), [1796](#), [1816](#),
[1822](#), [1824](#), [1827](#), [1836](#), [1840](#), [1853](#).
true: [479](#).
try_break: [1002](#), [1003](#), [1013](#), [1025](#), [1032](#), [1036](#),
[1040](#), [1042](#), [1043](#), [1047](#), [1053](#).
try_prev_break: [997](#), [1037](#).
two: [101](#), [102](#).
two_choices: [131](#).
two_halves: [131](#), [136](#), [142](#), [190](#), [239](#), [274](#), [275](#),
[858](#), [1096](#), [1141](#).
two_to_the: [117](#), [118](#), [120](#).
tx: [439](#), [450](#), [1255](#), [1256](#), [1257](#), [1281](#).
type: [4](#), [151](#), [152](#), [153](#), [154](#), [155](#), [156](#), [157](#), [158](#),
[159](#), [160](#), [161](#), [162](#), [163](#), [164](#), [165](#), [166](#), [167](#), [168](#),
[170](#), [171](#), [173](#), [174](#), [175](#), [176](#), [177](#), [178](#), [193](#), [201](#),
[202](#), [220](#), [224](#), [450](#), [497](#), [498](#), [515](#), [521](#), [522](#), [523](#),
[531](#), [650](#), [651](#), [654](#), [656](#), [659](#), [660](#), [663](#), [665](#), [668](#),
[674](#), [695](#), [705](#), [732](#), [733](#), [736](#), [737](#), [741](#), [742](#), [745](#),
[746](#), [751](#), [772](#), [821](#), [823](#), [825](#), [829](#), [842](#), [843](#),
[844](#), [854](#), [855](#), [856](#), [857](#), [860](#), [861](#), [862](#), [863](#),
[870](#), [872](#), [887](#), [889](#), [894](#), [895](#), [900](#), [901](#), [902](#),
[903](#), [905](#), [906](#), [910](#), [921](#), [924](#), [926](#), [934](#), [935](#),
[936](#), [941](#), [942](#), [970](#), [973](#), [975](#), [979](#), [981](#), [983](#),
[984](#), [985](#), [990](#), [993](#), [994](#), [996](#), [1003](#), [1004](#), [1006](#),
[1011](#), [1015](#), [1016](#), [1017](#), [1018](#), [1019](#), [1030](#), [1032](#),
[1033](#), [1034](#), [1035](#), [1036](#), [1038](#), [1039](#), [1040](#), [1042](#),
[1044](#), [1045](#), [1048](#), [1049](#), [1053](#), [1055](#), [1071](#), [1072](#),
[1074](#), [1078](#), [1089](#), [1143](#), [1145](#), [1147](#), [1148](#), [1151](#),
[1153](#), [1154](#), [1156](#), [1161](#), [1163](#), [1168](#), [1171](#), [1172](#),
[1175](#), [1179](#), [1183](#), [1184](#), [1185](#), [1186](#), [1188](#), [1189](#),
[1196](#), [1250](#), [1256](#), [1263](#), [1276](#), [1277](#), [1281](#), [1286](#),
[1289](#), [1297](#), [1323](#), [1331](#), [1334](#), [1335](#), [1339](#), [1341](#),
[1344](#), [1357](#), [1361](#), [1362](#), [1367](#), [1378](#), [1379](#), [1519](#),
[1527](#), [1571](#), [1632](#), [1633](#), [1634](#), [1676](#), [1688](#), [1696](#),
[1701](#), [1704](#), [1708](#), [1714](#), [1716](#), [1722](#), [1725](#), [1730](#),
[1735](#), [1736](#), [1743](#), [1774](#), [1785](#), [1786](#), [1812](#).
Type <return> to proceed... : [85](#).
u: [69](#), [107](#), [127](#), [415](#), [496](#), [586](#), [689](#), [706](#), [880](#), [965](#),
[974](#), [1104](#), [1109](#), [1119](#), [1433](#), [1741](#).
u_part: [942](#), [943](#), [953](#), [962](#), [968](#), [975](#).
u_template: [329](#), [336](#), [346](#), [962](#).
uc_code: [248](#), [250](#), [433](#).
\uccode primitive: [1406](#).
uc_code_base: [248](#), [253](#), [1406](#), [1407](#), [1462](#), [1464](#).
uc_hyph: [254](#), [1066](#), [1071](#).
\uchyph primitive: [256](#).
uc_hyph_code: [254](#), [255](#), [256](#).
un_hbox: [226](#), [1266](#), [1283](#), [1284](#), [1285](#).
\unhbox primitive: [1283](#).
\unhcopy primitive: [1283](#).
\unkern primitive: [1283](#).
\unpenalty primitive: [1283](#).
\unskip primitive: [1283](#).
un_vbox: [226](#), [1222](#), [1270](#), [1283](#), [1284](#), [1285](#), [1858](#).
\unvbox primitive: [1283](#).
\unvcopy primitive: [1283](#).

- unbalance*: [415](#), [417](#), [422](#), [425](#), [499](#), [503](#), [1680](#).
- Unbalanced output routine: [1202](#).
- Unbalanced write...: [1616](#).
- Undefined control sequence: [396](#).
- undefined_control_sequence*: [240](#), [250](#), [274](#), [276](#), [278](#), [284](#), [290](#), [304](#), [312](#), [1494](#), [1495](#).
- undefined_cs*: [228](#), [240](#), [388](#), [398](#), [527](#), [1402](#), [1403](#), [1471](#), [1763](#), [1764](#).
- undefined_primitive*: [275](#), [281](#), [394](#), [395](#), [527](#), [1221](#).
- under_noad*: [861](#), [864](#), [870](#), [872](#), [907](#), [935](#), [1332](#), [1333](#).
- Underfull \hbox...: [834](#).
- Underfull \vbox...: [848](#).
- \underline primitive: [1332](#).
- undump*: [1482](#), [1486](#), [1488](#), [1490](#), [1495](#), [1499](#), [1501](#), [1505](#), [1652](#).
- undump_end*: [1482](#).
- undump_end_end*: [1482](#).
- undump_four_ASCII*: [1486](#).
- undump_hh*: [1482](#), [1495](#), [1501](#).
- undump_int*: [1482](#), [1484](#), [1488](#), [1493](#), [1495](#), [1499](#), [1503](#), [1505](#).
- undump_qqqq*: [1482](#), [1486](#), [1499](#).
- undump_size*: [1482](#), [1486](#), [1497](#), [1501](#).
- undump_size_end*: [1482](#).
- undump_size_end_end*: [1482](#).
- undump_wd*: [1482](#), [1488](#), [1493](#), [1497](#).
- undumpimagemeta*: [1503](#).
- undumptonicode*: [1503](#).
- unescapehex*: [497](#).
- \unexpanded primitive: [1683](#).
- unfloat*: [109](#), [832](#), [838](#), [847](#), [850](#), [984](#), [985](#).
- unhyphenated*: [993](#), [1003](#), [1011](#), [1038](#), [1040](#), [1042](#).
- unif_rand*: [126](#), [498](#).
- \pdfuniformdeviate primitive: [494](#).
- uniform_deviate_code*: [494](#), [495](#), [497](#), [498](#).
- unity*: [101](#), [103](#), [119](#), [132](#), [182](#), [204](#), [479](#), [594](#), [1435](#).
- Unknown color stack: [1537](#).
- \unless primitive: [1759](#).
- unless_code*: [513](#), [514](#), [524](#), [1665](#), [1762](#).
- unpackage*: [1285](#), [1286](#).
- unsave*: [303](#), [305](#), [965](#), [974](#), [1201](#), [1239](#), [1244](#), [1262](#), [1276](#), [1295](#), [1309](#), [1344](#), [1350](#), [1362](#), [1367](#), [1370](#), [1372](#), [1376](#).
- unset_node*: [177](#), [193](#), [201](#), [202](#), [220](#), [224](#), [450](#), [823](#), [843](#), [856](#), [862](#), [863](#), [942](#), [970](#), [973](#), [975](#), [979](#).
- update_active*: [1035](#).
- update_adjust_list*: [829](#).
- update_heights*: [1145](#), [1147](#), [1148](#), [1169](#), [1172](#), [1175](#).
- update_image_procset*: [767](#).
- update_terminal*: [34](#), [37](#), [61](#), [71](#), [86](#), [384](#), [550](#), [563](#), [666](#), [674](#), [714](#), [750](#), [1456](#), [1516](#), [1752](#).
- update_width*: [1006](#), [1034](#).
- \uppercase primitive: [1462](#).
- Use of x doesn't match...: [424](#).
- use_err_help*: [79](#), [80](#), [89](#), [90](#), [1459](#).
- v*: [69](#), [107](#), [415](#), [476](#), [689](#), [880](#), [889](#), [910](#), [917](#), [923](#), [974](#), [1004](#), [1097](#), [1109](#), [1119](#), [1135](#), [1152](#), [1314](#), [1676](#).
- v_offset*: [265](#), [644](#), [668](#), [669](#), [755](#).
- \voffset primitive: [266](#).
- v_offset_code*: [265](#), [266](#).
- v_out*: [692](#), [693](#).
- v_part*: [942](#), [943](#), [953](#), [963](#), [968](#), [975](#).
- v_template*: [329](#), [336](#), [347](#), [416](#), [963](#), [1307](#).
- vacuous*: [466](#), [470](#), [471](#).
- vadjust*: [226](#), [287](#), [288](#), [1273](#), [1274](#), [1275](#), [1276](#).
- \vadjust primitive: [287](#).
- val*: [682](#).
- valign*: [226](#), [287](#), [288](#), [1222](#), [1266](#), [1306](#), [1697](#), [1698](#).
- \valign primitive: [287](#).
- var_code*: [250](#), [1327](#), [1331](#), [1341](#).
- var_delimiter*: [880](#), [911](#), [922](#), [936](#).
- var_used*: [135](#), [143](#), [148](#), [182](#), [667](#), [1487](#), [1488](#).
- vbadness*: [254](#), [848](#), [851](#), [852](#), [1187](#), [1192](#).
- \vbadness primitive: [256](#).
- vbadness_code*: [254](#), [255](#), [256](#).
- \vbox primitive: [1247](#).
- vbox_group*: [291](#), [1259](#), [1261](#), [1658](#), [1676](#).
- vcenter*: [226](#), [287](#), [288](#), [1222](#), [1343](#).
- \vcenter primitive: [287](#).
- vcenter_group*: [291](#), [1343](#), [1344](#), [1658](#), [1676](#).
- vcenter_noad*: [861](#), [864](#), [870](#), [872](#), [907](#), [935](#), [1344](#).
- vert_break*: [1145](#), [1146](#), [1151](#), [1152](#), [1155](#), [1157](#), [1185](#).
- very_loose_fit*: [991](#), [993](#), [1004](#), [1007](#), [1008](#), [1010](#), [1026](#), [1839](#), [1844](#).
- vet_glue*: [653](#), [662](#), [735](#), [744](#), [1635](#).
- vf_alpha*: [706](#).
- vf_b_open_in*: [713](#).
- vf_beta*: [706](#).
- vf_byte*: [712](#), [714](#), [715](#), [717](#).
- vf_cur_s*: [721](#), [723](#), [724](#), [725](#).
- vf_def_font*: [712](#), [715](#).
- vf_default_font*: [705](#), [706](#), [710](#), [715](#), [719](#), [720](#), [725](#), [726](#).
- vf_e_fnts*: [706](#), [710](#), [715](#), [719](#), [720](#), [726](#).
- vf_error*: [710](#), [712](#).
- vf_expand_local_fonts*: [705](#).
- vf_f*: [725](#), [726](#).
- vf_file*: [710](#), [712](#), [713](#).
- vf_i_fnts*: [705](#), [706](#), [710](#), [715](#), [720](#), [725](#), [726](#).
- vf_id*: [710](#), [714](#).

- vf_local_font_num*: [705](#), [706](#), [710](#), [715](#), [719](#), [720](#), [726](#).
- vf_local_font_warning*: [712](#).
- vf_max_packet_length*: [710](#), [717](#), [719](#).
- vf_max_recursion*: [721](#), [723](#), [725](#).
- vf_nf*: [706](#), [710](#), [711](#), [715](#), [720](#).
- vf_packet_base*: [706](#), [710](#), [716](#), [720](#).
- vf_packet_length*: [710](#), [725](#).
- vf_read_signed*: [712](#), [714](#), [717](#).
- vf_read_unsigned*: [712](#), [715](#), [717](#), [719](#).
- vf_replace_z*: [706](#).
- vf_stack*: [723](#), [726](#).
- vf_stack_index*: [712](#), [722](#), [723](#).
- vf_stack_ptr*: [723](#), [724](#), [726](#).
- vf_stack_record*: [722](#), [723](#).
- vf_stack_size*: [719](#), [721](#), [722](#).
- vf_z*: [706](#).
- \vfil* primitive: [1234](#).
- \vfilneg* primitive: [1234](#).
- \vfill* primitive: [1234](#).
- vfuzz*: [265](#), [851](#), [1187](#), [1192](#).
- \vfuzz* primitive: [266](#).
- vfuzz_code*: [265](#), [266](#).
- VIRTEX**: [1509](#).
- virtual memory: [144](#).
- virtual_font_type*: [703](#), [705](#), [706](#), [712](#), [720](#), [726](#).
- Vitter, Jeffrey Scott: [280](#).
- vlist_node*: [155](#), [166](#), [177](#), [193](#), [201](#), [202](#), [220](#), [224](#), [531](#), [646](#), [650](#), [651](#), [656](#), [657](#), [659](#), [660](#), [665](#), [668](#), [732](#), [733](#), [737](#), [741](#), [742](#), [746](#), [751](#), [814](#), [823](#), [842](#), [843](#), [855](#), [887](#), [889](#), [894](#), [910](#), [921](#), [924](#), [981](#), [983](#), [985](#), [1015](#), [1016](#), [1040](#), [1044](#), [1045](#), [1143](#), [1148](#), [1153](#), [1175](#), [1250](#), [1256](#), [1263](#), [1286](#), [1323](#), [1634](#), [1722](#), [1730](#).
- vlist_out*: [619](#), [642](#), [643](#), [646](#), [647](#), [651](#), [656](#), [657](#), [660](#), [665](#), [666](#), [668](#), [727](#), [728](#), [867](#), [1617](#).
- vmode*: [229](#), [233](#), [442](#), [443](#), [444](#), [448](#), [450](#), [527](#), [949](#), [959](#), [960](#), [978](#), [981](#), [982](#), [983](#), [986](#), [1200](#), [1204](#), [1221](#), [1222](#), [1224](#), [1232](#), [1233](#), [1247](#), [1248](#), [1249](#), [1252](#), [1254](#), [1255](#), [1256](#), [1259](#), [1266](#), [1267](#), [1270](#), [1274](#), [1275](#), [1279](#), [1281](#), [1285](#), [1286](#), [1287](#), [1306](#), [1343](#), [1419](#), [1420](#), [1558](#), [1559](#), [1676](#), [1678](#).
- vmove*: [226](#), [1224](#), [1247](#), [1248](#), [1249](#), [1678](#).
- vpack*: [254](#), [814](#), [815](#), [816](#), [842](#), [879](#), [909](#), [912](#), [933](#), [973](#), [978](#), [1152](#), [1196](#), [1276](#), [1344](#).
- vpackage*: [842](#), [970](#), [1152](#), [1192](#), [1262](#).
- vrule*: [226](#), [287](#), [288](#), [489](#), [1232](#), [1260](#), [1266](#).
- \vrule* primitive: [287](#).
- vsize*: [265](#), [1155](#), [1162](#).
- \vsize* primitive: [266](#).
- vsize_code*: [265](#), [266](#).
- vskip*: [226](#), [1222](#), [1233](#), [1234](#), [1235](#), [1254](#), [1270](#).
- \vskip* primitive: [1234](#).
- vsplit*: [1142](#), [1152](#), [1153](#), [1155](#), [1258](#), [1806](#), [1822](#), [1823](#).
- \vsplit* needs a *\vbox*: [1153](#).
- \vsplit* primitive: [1247](#).
- vsplit_code*: [1247](#), [1248](#), [1255](#), [1513](#), [1856](#), [1858](#), [1859](#).
- vsplit_init*: [1152](#), [1822](#), [1823](#).
- \vss* primitive: [1234](#).
- \vtop* primitive: [1247](#).
- vtop_code*: [1247](#), [1248](#), [1259](#), [1261](#), [1262](#).
- vtop_group*: [291](#), [1259](#), [1261](#), [1658](#), [1676](#).
- w*: [132](#), [165](#), [174](#), [297](#), [300](#), [301](#), [634](#), [690](#), [821](#), [842](#), [880](#), [889](#), [912](#), [965](#), [974](#), [1081](#), [1169](#), [1299](#), [1314](#), [1374](#), [1412](#), [1478](#), [1479](#), [1527](#), [1528](#), [1680](#), [1716](#), [1750](#), [1753](#), [1771](#), [1773](#), [1816](#), [1836](#), [1837](#).
- w_close*: [28](#), [1507](#), [1515](#).
- w_make_name_string*: [551](#), [1506](#).
- w_open_in*: [27](#), [550](#).
- w_open_out*: [27](#), [1506](#).
- wait*: [1187](#), [1195](#), [1196](#), [1197](#).
- wake_up_terminal*: [34](#), [37](#), [51](#), [71](#), [73](#), [385](#), [510](#), [550](#), [556](#), [686](#), [1470](#), [1473](#), [1479](#), [1511](#), [1516](#).
- warn*: [693](#).
- warn_dest_dup*: [1562](#), [1563](#), [1634](#).
- warn_pdfpagebox*: [1548](#), [1549](#), [1550](#).
- Warning**: end of file when...: [1774](#).
- Warning**: end of...: [1771](#), [1773](#).
- warning_index*: [327](#), [353](#), [360](#), [415](#), [416](#), [421](#), [422](#), [424](#), [427](#), [497](#), [499](#), [505](#), [508](#), [948](#), [951](#), [1680](#).
- warning_issued*: [76](#), [263](#), [686](#), [1513](#), [1771](#), [1773](#), [1774](#).
- was_free*: [183](#), [185](#), [189](#).
- was_hi_min*: [183](#), [184](#), [185](#), [189](#).
- was_lo_max*: [183](#), [184](#), [185](#), [189](#).
- was_mem_end*: [183](#), [184](#), [185](#), [189](#).
- \wd* primitive: [442](#).
- WEB**: [1](#), [4](#), [38](#), [40](#), [50](#), [1484](#).
- what_lang*: [1519](#), [1600](#), [1606](#), [1607](#), [1621](#), [1622](#).
- what_lhm*: [1519](#), [1600](#), [1606](#), [1607](#), [1621](#), [1622](#).
- what_rhm*: [1519](#), [1600](#), [1606](#), [1607](#), [1621](#), [1622](#).
- whatsit_node*: [164](#), [166](#), [193](#), [201](#), [220](#), [224](#), [650](#), [659](#), [732](#), [741](#), [772](#), [823](#), [843](#), [904](#), [935](#), [1003](#), [1040](#), [1071](#), [1074](#), [1143](#), [1148](#), [1175](#), [1323](#), [1519](#), [1527](#), [1571](#), [1632](#), [1634](#), [1697](#), [1730](#).
- \widowpenalties* primitive: [1861](#).
- widow_penalties_loc*: [248](#), [1861](#), [1862](#).
- widow_penalties_ptr*: [1065](#), [1861](#).
- widow_penalty*: [254](#), [988](#), [1065](#).
- \widowpenalty* primitive: [256](#).
- widow_penalty_code*: [254](#), [255](#), [256](#).
- width*: [489](#).

width: [153](#), [154](#), [156](#), [157](#), [165](#), [168](#), [169](#), [173](#), [174](#),
[196](#), [201](#), [202](#), [205](#), [209](#), [210](#), [450](#), [455](#), [457](#), [477](#),
[488](#), [489](#), [498](#), [580](#), [632](#), [634](#), [638](#), [644](#), [650](#), [651](#),
[653](#), [654](#), [659](#), [661](#), [662](#), [663](#), [669](#), [705](#), [732](#), [733](#),
[735](#), [736](#), [741](#), [743](#), [744](#), [745](#), [752](#), [755](#), [821](#), [823](#),
[825](#), [830](#), [831](#), [840](#), [842](#), [843](#), [844](#), [845](#), [853](#), [857](#),
[862](#), [880](#), [883](#), [888](#), [889](#), [890](#), [891](#), [905](#), [912](#), [918](#),
[921](#), [923](#), [924](#), [931](#), [932](#), [933](#), [942](#), [953](#), [967](#), [970](#),
[971](#), [972](#), [975](#), [976](#), [977](#), [978](#), [980](#), [981](#), [982](#), [983](#),
[984](#), [985](#), [1001](#), [1003](#), [1011](#), [1012](#), [1015](#), [1016](#),
[1040](#), [1042](#), [1044](#), [1045](#), [1055](#), [1144](#), [1151](#), [1171](#),
[1176](#), [1179](#), [1184](#), [1218](#), [1220](#), [1230](#), [1267](#), [1269](#),
[1323](#), [1324](#), [1375](#), [1377](#), [1381](#), [1405](#), [1415](#), [1416](#),
[1546](#), [1550](#), [1554](#), [1563](#), [1571](#), [1627](#), [1634](#), [1635](#),
[1696](#), [1711](#), [1713](#), [1716](#), [1717](#), [1718](#), [1719](#), [1722](#),
[1725](#), [1726](#), [1731](#), [1733](#), [1735](#), [1737](#), [1742](#), [1743](#),
[1777](#), [1787](#), [1791](#), [1792](#), [1793](#), [1795](#), [1850](#).
width_base: [576](#), [578](#), [580](#), [592](#), [595](#), [598](#), [603](#),
[705](#), [706](#), [1498](#), [1499](#).
width_index: [569](#), [576](#).
width_offset: [153](#), [442](#), [443](#), [1423](#).
Wirth, Niklaus: [10](#).
wlog: [56](#), [58](#), [562](#), [1511](#), [1512](#).
wlog_cr: [56](#), [57](#), [58](#), [562](#), [1511](#).
wlog_ln: [56](#), [1511](#), [1512](#).
word_define: [1390](#), [1404](#), [1408](#), [1836](#).
word_file: [25](#), [27](#), [28](#), [131](#), [551](#), [1481](#).
word_node_size: [1817](#), [1818](#), [1834](#), [1838](#).
words: [222](#), [223](#), [224](#), [1601](#), [1730](#).
wrap_lig: [1085](#), [1086](#).
wrapup: [1210](#), [1215](#), [1216](#).
write: [37](#), [56](#), [58](#), [624](#).
\write primitive: [1522](#).
write_action: [782](#), [1561](#), [1577](#), [1627](#).
write_dvi: [624](#), [625](#), [626](#).
write_file: [57](#), [58](#), [1520](#), [1619](#), [1623](#).
write_fontstuff: [799](#).
write_image: [778](#).
write_ln: [35](#), [37](#), [51](#), [56](#), [57](#).
write_loc: [1489](#), [1490](#), [1522](#), [1523](#), [1615](#).
write_node: [1519](#), [1522](#), [1524](#), [1526](#), [1600](#), [1601](#),
[1602](#), [1617](#), [1619](#).
write_node_size: [1519](#), [1528](#), [1530](#), [1531](#), [1532](#),
[1536](#), [1601](#), [1602](#).
write_open: [1520](#), [1521](#), [1614](#), [1619](#), [1623](#).
write_out: [1614](#), [1619](#).
write_pdf: [685](#).
write_stream: [1519](#), [1528](#), [1532](#), [1599](#), [1614](#), [1619](#).
write_stream_length: [685](#).
write_text: [329](#), [336](#), [345](#), [1518](#), [1615](#).
write_tokens: [727](#), [1519](#), [1530](#), [1531](#), [1532](#), [1600](#),
[1601](#), [1602](#), [1612](#), [1615](#).

write_zip: [685](#).
writing: [605](#).
wterm: [56](#), [58](#), [61](#).
wterm_cr: [56](#), [57](#), [58](#).
wterm_ln: [56](#), [61](#), [550](#), [1479](#), [1510](#), [1515](#).
Wyatt, Douglas Kirk: [2](#).
w0: [612](#), [613](#), [631](#), [636](#), [719](#), [726](#).
w1: [612](#), [613](#), [634](#), [719](#), [726](#).
w2: [612](#).
w3: [612](#).
w4: [612](#).
x: [100](#), [105](#), [106](#), [107](#), [119](#), [124](#), [126](#), [127](#), [614](#),
[627](#), [689](#), [821](#), [842](#), [880](#), [894](#), [900](#), [909](#), [911](#),
[912](#), [917](#), [923](#), [930](#), [1299](#), [1314](#), [1478](#), [1479](#),
[1550](#), [1741](#), [1790](#), [1796](#).
x_height: [573](#), [584](#), [585](#), [673](#), [693](#), [912](#), [1299](#).
x_height_code: [573](#), [584](#).
x_leaders: [167](#), [208](#), [655](#), [1247](#), [1248](#).
\leaders primitive: [1247](#).
x_over_n: [106](#), [877](#), [890](#), [891](#), [1161](#), [1183](#), [1184](#),
[1185](#), [1416](#).
x_token: [386](#), [407](#), [504](#), [1213](#), [1328](#).
xchr: [20](#), [21](#), [23](#), [24](#), [38](#), [49](#), [58](#), [545](#).
xclause: [16](#).
\xdef primitive: [1384](#).
seq_level: [271](#), [272](#), [290](#), [300](#), [301](#), [305](#), [1480](#).
rn_over_d: [107](#), [481](#), [483](#), [484](#), [594](#), [890](#), [1220](#),
[1436](#).
xord: [20](#), [24](#), [31](#), [52](#), [53](#), [549](#), [551](#).
xpand: [499](#), [503](#), [505](#).
xr: [1550](#).
xray: [226](#), [1466](#), [1467](#), [1468](#), [1672](#), [1681](#), [1686](#).
xrealloc_array: [678](#), [686](#), [698](#), [1503](#).
xref_offset_width: [812](#), [1511](#).
xspace_skip: [242](#), [1219](#).
\xspaceskip primitive: [244](#).
xspace_skip_code: [242](#), [243](#), [244](#), [1219](#).
xxx1: [612](#), [613](#), [719](#), [726](#), [1612](#).
xxx2: [612](#).
xxx3: [612](#).
xxx4: [612](#), [613](#), [1612](#).
x0: [612](#), [613](#), [631](#), [636](#), [719](#), [726](#).
x1: [612](#), [613](#), [634](#), [719](#), [726](#).
x2: [612](#).
x3: [612](#).
x4: [612](#).
y: [105](#), [119](#), [126](#), [880](#), [900](#), [909](#), [911](#), [912](#), [917](#),
[923](#), [930](#), [1790](#).
y_here: [635](#), [636](#), [638](#), [639](#), [640](#).
y_OK: [635](#), [636](#), [639](#).
y_seen: [638](#), [639](#).
year: [254](#), [259](#), [645](#), [792](#), [1506](#).

`\year` primitive: [256](#).
`year_code`: [254](#), [255](#), [256](#).
You already have nine...: [502](#).
You can't `\insert255`: [1275](#).
You can't dump...: [1480](#).
You can't use `\hrule`...: [1271](#).
You can't use `\long`...: [1389](#).
You can't use `\unless`...: [1762](#).
You can't use a prefix with `x`: [1388](#).
You can't use `x` after ...: [454](#), [1413](#).
You can't use `x` in `y` mode: [1225](#).
You have to increase `POOLSIZE`: [52](#).
You want to edit file `x`: [84](#).
`you_cant`: [1225](#), [1226](#), [1256](#), [1282](#).
`yr`: [1550](#).
`yz_OK`: [635](#), [636](#), [637](#), [639](#).
`y0`: [612](#), [613](#), [621](#), [631](#), [636](#), [719](#), [726](#).
`y1`: [612](#), [613](#), [634](#), [640](#), [719](#), [726](#).
`y2`: [612](#), [621](#).
`y3`: [612](#).
`y4`: [612](#).
`z`: [119](#), [586](#), [880](#), [900](#), [917](#), [923](#), [930](#), [1097](#), [1102](#),
[1128](#), [1134](#), [1374](#), [1741](#).
`z_here`: [635](#), [636](#), [638](#), [639](#), [641](#).
`z_OK`: [635](#), [636](#), [639](#).
`z_seen`: [638](#), [639](#).
Zabala Salelles, Ignacio Andrés: [2](#).
`zero_glue`: [180](#), [193](#), [242](#), [246](#), [450](#), [453](#), [488](#), [906](#),
[976](#), [1003](#), [1061](#), [1217](#), [1218](#), [1219](#), [1347](#), [1405](#),
[1737](#), [1779](#), [1787](#), [1806](#), [1817](#), [1818](#).
`zero_token`: [471](#), [478](#), [499](#), [502](#), [505](#).
`zip_finish`: [680](#), [685](#).
`zip_write_state`: [679](#), [680](#), [681](#), [685](#).
`zip_writing`: [680](#), [685](#).
`z0`: [612](#), [613](#), [631](#), [636](#), [719](#), [726](#).
`z1`: [612](#), [613](#), [634](#), [641](#), [719](#), [726](#).
`z2`: [612](#).
`z3`: [612](#).
`z4`: [612](#).

- <(pdfTeX) Move down or output leaders 744> Used in section 741.
- <(pdfTeX) Move right or output leaders 735> Used in section 732.
- <(pdfTeX) Output a box in a vlist 742> Used in section 741.
- <(pdfTeX) Output a box in an hlist 733> Used in section 732.
- <(pdfTeX) Output a leader box at *cur_h*, then advance *cur_h* by *leader_wd* + *lx* 737> Used in section 736.
- <(pdfTeX) Output a leader box at *cur_v*, then advance *cur_v* by *leader_ht* + *lx* 746> Used in section 745.
- <(pdfTeX) Output a rule in a vlist, **goto** *next_p* 743> Used in section 741.
- <(pdfTeX) Output a rule in an hlist 734> Used in section 732.
- <(pdfTeX) Output leaders in a vlist, **goto** *fin_rule* if a rule or to *next_p* if done 745> Used in section 744.
- <(pdfTeX) Output leaders in an hlist, **goto** *fin_rule* if a rule or to *next_p* if done 736> Used in section 735.
- <(pdfTeX) Ship box *p* out 751> Used in section 750.
- <Accumulate the constant until *cur_tok* is not a suitable digit 471> Used in section 470.
- <Add the width of node *s* to *act_width* 1045> Used in section 1043.
- <Add the width of node *s* to *break_width* 1016> Used in section 1014.
- <Add the width of node *s* to *disc_width* 1044> Used in section 1043.
- <Adjust for the magnification ratio 483> Used in section 479.
- <Adjust for the setting of `\globaldefs` 1390> Used in section 1387.
- <Adjust *shift_up* and *shift_down* for the case of a fraction line 920> Used in section 917.
- <Adjust *shift_up* and *shift_down* for the case of no fraction line 919> Used in section 917.
- <Adjust the LR stack for the *hlist_out* routine; if necessary reverse an hlist segment and **goto** *reswitch* 1714>
Used in section 1713.
- <Adjust the LR stack for the *hpack* routine 1708> Used in section 823.
- <Adjust the LR stack for the *init_math* routine 1734> Used in section 1733.
- <Adjust the LR stack for the *just_reverse* routine 1736> Used in section 1735.
- <Adjust the LR stack for the *post_line_break* routine 1705> Used in sections 1053, 1055, and 1704.
- <Adjust the additional data for last line 1846> Used in section 1025.
- <Adjust the final line of the paragraph 1850> Used in section 1037.
- <Adjust transformation matrix for the magnification ratio 758> Used in section 757.
- <Advance *cur_p* to the node following the present string of characters 1041> Used in section 1040.
- <Advance past a whatsit node in the *line_break* loop 1606> Used in section 1040.
- <Advance past a whatsit node in the pre-hyphenation loop 1607> Used in section 1071.
- <Advance *r*; **goto** *found* if the parameter delimiter has been fully matched, otherwise **goto** *continue* 420>
Used in section 418.
- <Allocate entire node *p* and **goto** *found* 147> Used in section 145.
- <Allocate from the top of node *p* and **goto** *found* 146> Used in section 145.
- <Allocate memory for the new virtual font 716> Used in section 712.
- <Apologize for inability to do the operation now, unless `\unskip` follows non-glue 1282> Used in section 1281.
- <Apologize for not loading the font, **goto** *done* 593> Used in section 592.
- <Append a ligature and/or kern to the translation; **goto** *continue* if the stack of inserted ligatures is nonempty 1085> Used in section 1081.
- <Append a new leader node that uses *cur_box* 1254> Used in section 1251.
- <Append a new letter or a hyphen level 1137> Used in section 1136.
- <Append a new letter or hyphen 1112> Used in section 1110.
- <Append a normal inter-word space to the current list, then **goto** *big_switch* 1217> Used in section 1205.
- <Append a penalty node, if a nonzero penalty is appropriate 1065> Used in section 1054.
- <Append an insertion to the current page and **goto** *contribute* 1183> Used in section 1175.
- <Append any *new_hlist* entries for *q*, and any appropriate penalties 941> Used in section 934.
- <Append box *cur_box* to the current list, shifted by *box_context* 1252> Used in section 1251.
- <Append character *cur_chr* and the following characters (if any) to the current hlist in the current font; **goto** *reswitch* when a non-character has been fetched 1209> Used in section 1205.
- <Append characters of *hu[j ..]* to *major_tail*, advancing *j* 1092> Used in section 1091.
- <Append inter-element spacing based on *r_type* and *t* 940> Used in section 934.

- < Append tabskip glue and an empty box to list u , and update s and t as the prototype nodes are passed 983 >
Used in section 982.
- < Append the accent with appropriate kerns, then set $p \leftarrow q$ 1301 > Used in section 1299.
- < Append the current tabskip glue to the preamble list 952 > Used in section 951.
- < Append the display and perhaps also the equation number 1380 > Used in section 1375.
- < Append the glue or equation number following the display 1381 > Used in section 1375.
- < Append the glue or equation number preceding the display 1379 > Used in section 1375.
- < Append the new box to the current vertical list, followed by the list of special nodes taken out of the box by the packager 1063 > Used in section 1054.
- < Append the value n to list p 1113 > Used in section 1112.
- < Assign the values $depth_threshold \leftarrow show_box_depth$ and $breadth_max \leftarrow show_box_breadth$ 254 > Used in section 216.
- < Assignments 1393, 1394, 1397, 1400, 1401, 1402, 1404, 1408, 1410, 1411, 1417, 1418, 1424, 1428, 1429, 1432, 1440 > Used in section 1387.
- < Attach list p to the current list, and record its length; then finish up and **return** 1296 > Used in section 1295.
- < Attach the limits to y and adjust $height(v)$, $depth(v)$ to account for their presence 925 > Used in section 924.
- < Back up an outer control sequence so that it can be reread 359 > Used in section 358.
- < Basic printing procedures 57, 58, 59, 60, 62, 63, 64, 65, 284, 285, 544, 873, 1599, 1819 > Used in section 4.
- < Break the current page at node p , put it in box 255, and put the remaining nodes on the contribution list 1192 > Used in section 1189.
- < Break the paragraph at the chosen breakpoints, justify the resulting lines to the correct widths, and append them to the current vertical list 1050 > Used in section 989.
- < Build a character packet 717 > Used in section 712.
- < Build a linked list of free objects 810 > Used in sections 811 and 812.
- < Calculate DVI page dimensions and margins 644 > Used in section 645.
- < Calculate page dimensions and margins 755 > Used in section 752.
- < Calculate the length, l , and the shift amount, s , of the display lines 1325 > Used in section 1321.
- < Calculate the natural width, w , by which the characters of the final line extend to the right of the reference point, plus two ems; or set $w \leftarrow max_dimen$ if the non-blank information on that line is affected by stretching or shrinking 1322 > Used in section 1321.
- < Calculate variations of marginal kerns 820 > Used in section 1025.
- < Call the packaging subroutine, setting $just_box$ to the justified box 1064 > Used in section 1054.
- < Call try_break if cur_p is a legal breakpoint; on the second pass, also try to hyphenate the next word, if cur_p is a glue node; then advance cur_p to the next node of the paragraph that could possibly be a legal breakpoint 1040 > Used in section 1037.
- < Carry out a ligature replacement, updating the cursor structure and possibly advancing j ; **goto** *continue* if the cursor doesn't advance, otherwise **goto** *done* 1086 > Used in section 1084.
- < Case statement to copy different types and set *words* to the number of initial words not yet copied 224 >
Used in section 223.
- < Cases for 'Fetch the *dead_cycles* or the *insert_penalties*' 1691 > Used in section 445.
- < Cases for evaluation of the current term 1788, 1792, 1793, 1795 > Used in section 1780.
- < Cases for fetching a dimension value 1668, 1671, 1801 > Used in section 450.
- < Cases for fetching a glue value 1804 > Used in section 1777.
- < Cases for fetching a mu value 1805 > Used in section 1777.
- < Cases for fetching an integer value 1648, 1662, 1665, 1800 > Used in section 450.
- < Cases for noads that can follow a *bin_noad* 907 > Used in section 902.
- < Cases for nodes that can appear in an mlist, after which we **goto** *done_with_node* 904 > Used in section 902.
- < Cases for *alter_integer* 1693 > Used in section 1422.
- < Cases for *conditional* 1763, 1764, 1766 > Used in section 527.
- < Cases for *do_marks* 1823, 1825, 1826, 1828 > Used in section 1822.
- < Cases for *eq_destroy* 1831 > Used in section 297.
- < Cases for *input* 1746 > Used in section 404.

- < Cases for *print_param* 1656, 1697 > Used in section 255.
- < Cases for *show_whatever* 1674, 1688 > Used in section 1469.
- < Cases of DVI commands that can appear in character packet 719 > Used in section 717.
- < Cases of ‘Let *d* be the natural width’ that need special treatment 1733 > Used in section 1323.
- < Cases of *assign_toks* for *print_cmd_chr* 1655 > Used in section 249.
- < Cases of *expandafter* for *print_cmd_chr* 1760 > Used in section 288.
- < Cases of *flush_node_list* that arise in mlists only 872 > Used in section 220.
- < Cases of *handle_right_brace* where a *right_brace* triggers a delayed action 1261, 1276, 1294, 1308, 1309, 1344, 1349, 1362 > Used in section 1244.
- < Cases of *hlist_out* that arise in mixed direction text only 1717 > Used in sections 650 and 732.
- < Cases of *if_test* for *print_cmd_chr* 1761 > Used in section 514.
- < Cases of *input* for *print_cmd_chr* 1745 > Used in section 403.
- < Cases of *last_item* for *print_cmd_chr* 1647, 1661, 1664, 1667, 1670, 1776, 1799, 1803 > Used in section 443.
- < Cases of *left_right* for *print_cmd_chr* 1695 > Used in section 1365.
- < Cases of *main_control* for *hmode* + *valign* 1700 > Used in section 1306.
- < Cases of *main_control* that are for extensions to T_EX 1525 > Used in section 1221.
- < Cases of *main_control* that are not part of the inner loop 1221 > Used in section 1205.
- < Cases of *main_control* that build boxes and lists 1232, 1233, 1239, 1243, 1249, 1266, 1268, 1270, 1273, 1278, 1280, 1285, 1288, 1292, 1298, 1302, 1306, 1310, 1313, 1316, 1326, 1330, 1334, 1338, 1340, 1343, 1347, 1351, 1356, 1366, 1369 > Used in section 1221.
- < Cases of *main_control* that don’t depend on *mode* 1386, 1444, 1447, 1450, 1452, 1461, 1466 > Used in section 1221.
- < Cases of *prefix* for *print_cmd_chr* 1768 > Used in section 1385.
- < Cases of *print_cmd_chr* for symbolic printing of primitives 245, 249, 257, 267, 288, 357, 403, 411, 438, 443, 495, 514, 518, 955, 1159, 1229, 1235, 1248, 1265, 1284, 1291, 1319, 1333, 1346, 1355, 1365, 1385, 1396, 1399, 1407, 1427, 1431, 1437, 1439, 1449, 1454, 1463, 1468, 1471, 1524 > Used in section 320.
- < Cases of *read* for *print_cmd_chr* 1757 > Used in section 288.
- < Cases of *register* for *print_cmd_chr* 1829 > Used in section 438.
- < Cases of *reverse* that need special treatment 1723, 1724, 1725 > Used in section 1722.
- < Cases of *set_page_int* for *print_cmd_chr* 1690 > Used in section 443.
- < Cases of *set_shape* for *print_cmd_chr* 1862 > Used in section 288.
- < Cases of *show_node_list* that arise in mlists only 864 > Used in section 201.
- < Cases of *the* for *print_cmd_chr* 1684 > Used in section 288.
- < Cases of *toks_register* for *print_cmd_chr* 1830 > Used in section 288.
- < Cases of *un_vbox* for *print_cmd_chr* 1859 > Used in section 1284.
- < Cases of *valign* for *print_cmd_chr* 1699 > Used in section 288.
- < Cases of *xray* for *print_cmd_chr* 1673, 1682, 1687 > Used in section 1468.
- < Cases where character is ignored 367 > Used in section 366.
- < Change buffered instruction to *y* or *w* and **goto found** 640 > Used in section 639.
- < Change buffered instruction to *z* or *x* and **goto found** 641 > Used in section 639.
- < Change current mode to *-vmode* for **\halign**, *-hmode* for **\valign** 949 > Used in section 948.
- < Change discretionary to compulsory and set *disc_break* \leftarrow *true* 1056 > Used in section 1055.
- < Change font *dvi_f* to *f* 649 > Used in section 648.
- < Change state if necessary, and **goto switch** if the current character should be ignored, or **goto reswitch** if the current character changes to another 366 > Used in section 365.
- < Change the case of the token in *p*, if a change is appropriate 1465 > Used in section 1464.
- < Change the current style and **goto delete_q** 937 > Used in section 935.
- < Change the interaction level and **return** 86 > Used in section 84.
- < Change this node to a style node followed by the correct choice, then **goto done_with_node** 905 > Used in section 904.
- < Character *k* cannot be printed 49 > Used in section 48.
- < Character *s* is the current new-line character 262 > Used in sections 58 and 59.
- < Check flags of unavailable nodes 188 > Used in section 185.

- < Check for LR anomalies at the end of *hlist_out* 1715 > Used in section 1712.
- < Check for LR anomalies at the end of *hpack* 1709 > Used in section 821.
- < Check for LR anomalies at the end of *ship_out* 1727 > Used in sections 666 and 750.
- < Check for charlist cycle 596 > Used in section 595.
- < Check for improper alignment in displayed math 950 > Used in section 948.
- < Check for non-existing destinations 796 > Used in section 794.
- < Check for non-existing pages 797 > Used in section 794.
- < Check for special treatment of last line of paragraph 1840 > Used in section 1001.
- < Check if node p is a new champion breakpoint; then **goto** *done* if p is a forced break or if the page-so-far is already too full 1149 > Used in section 1147.
- < Check if node p is a new champion breakpoint; then if it is time for a page break, prepare for output, and either fire up the user's output routine and **return** or ship out the page and **goto** *done* 1180 > Used in section 1172.
- < Check single-word *avail* list 186 > Used in section 185.
- < Check that another \$ follows 1373 > Used in sections 1370, 1370, and 1382.
- < Check that the necessary fonts for math symbols are present; if not, flush the current math lists and set *danger* \leftarrow *true* 1371 > Used in sections 1370 and 1370.
- < Check that the nodes following *hb* permit hyphenation and that at least $l_{hyf} + r_{hyf}$ letters have been found, otherwise **goto** *done1* 1074 > Used in section 1069.
- < Check the "constant" values for consistency 14, 129, 312, 548, 1425 > Used in section 1510.
- < Check the pool check sum 53 > Used in section 52.
- < Check variable-size *avail* list 187 > Used in section 185.
- < Clean up the memory by removing the break nodes 1039 > Used in sections 989 and 1037.
- < Clear dimensions to zero 822 > Used in sections 821 and 842.
- < Clear off top level from *save_stack* 304 > Used in section 303.
- < Close the format file 1507 > Used in section 1478.
- < Coerce glue to a dimension 477 > Used in sections 475 and 481.
- < Compiler directives 9 > Used in section 4.
- < Complain about an undefined family and set *cur_i* null 897 > Used in section 896.
- < Complain about an undefined macro 396 > Used in section 391.
- < Complain about missing **\endcsname** 399 > Used in sections 398 and 1764.
- < Complain about unknown unit and **goto** *done2* 485 > Used in section 484.
- < Complain that **\the** can't do this; give zero result 454 > Used in section 439.
- < Complain that the user should have said **\mathaccent** 1342 > Used in section 1341.
- < Compleat the incompleat noad 1361 > Used in section 1360.
- < Complete a potentially long **\show** command 1474 > Used in section 1469.
- < Compute $f = \lfloor 2^{28}(1 + p/q) + \frac{1}{2} \rfloor$ 113 > Used in section 112.
- < Compute $p = \lfloor qf/2^{28} + \frac{1}{2} \rfloor - q$ 116 > Used in section 114.
- < Compute $f = \lfloor xn/d + \frac{1}{2} \rfloor$ 1797 > Used in section 1796.
- < Compute result of *multiply* or *divide*, put it in *cur_val* 1416 > Used in section 1412.
- < Compute result of *register* or *advance*, put it in *cur_val* 1414 > Used in section 1412.
- < Compute the amount of skew 915 > Used in section 912.
- < Compute the badness, b , of the current page, using *awful_bad* if the box is too full 1182 > Used in section 1180.
- < Compute the badness, b , using *awful_bad* if the box is too full 1150 > Used in section 1149.
- < Compute the demerits, d , from r to *cur_p* 1033 > Used in section 1029.
- < Compute the discretionary *break_width* values 1014 > Used in section 1011.
- < Compute the hash code h 280 > Used in section 278.
- < Compute the magic offset 939 > Used in section 1515.
- < Compute the mark pointer for mark type t and class *cur_val* 1821 > Used in section 412.
- < Compute the minimum suitable height, w , and the corresponding number of extension steps, n ; also set *width(b)* 888 > Used in section 887.
- < Compute the new line width 1024 > Used in section 1009.

- < Compute the primitive code *h* 283 > Used in section 281.
- < Compute the register location *l* and its type *p*; but **return** if invalid 1413 > Used in section 1412.
- < Compute the sum of two glue specs 1415 > Used in section 1414.
- < Compute the sum or difference of two glue specs 1791 > Used in section 1789.
- < Compute the trie op code, *v*, and set $l \leftarrow 0$ 1140 > Used in section 1138.
- < Compute the values of *break_width* 1011 > Used in section 1010.
- < Consider a node with matching width; **goto found** if it's a hit 639 > Used in section 638.
- < Consider the demerits for a line from *r* to *cur_p*; deactivate node *r* if it should no longer be active; then **goto continue** if a line from *r* to *cur_p* is infeasible, otherwise record a new feasible break 1025 > Used in section 1003.
- < Constants in the outer block 11, 675, 679, 695, 721, 1628 > Used in section 4.
- < Construct a box with limits above and below it, skewed by *delta* 924 > Used in section 923.
- < Construct a sub/superscript combination box *x*, with the superscript offset by *delta* 933 > Used in section 930.
- < Construct a subscript box *x* when there is no superscript 931 > Used in section 930.
- < Construct a superscript box *x* 932 > Used in section 930.
- < Construct a vlist box for the fraction, according to *shift_up* and *shift_down* 921 > Used in section 917.
- < Construct an extensible character in a new box *b*, using recipe *rem_byte(q)* and font *f* 887 > Used in section 884.
- < Contribute an entire group to the current parameter 425 > Used in section 418.
- < Contribute the recently matched tokens to the current parameter, and **goto continue** if a partial match is still in effect; but abort if *s = null* 423 > Used in section 418.
- < Convert a final *bin_noad* to an *ord_noad* 903 > Used in sections 900 and 902.
- < Convert *cur_val* to a lower level 455 > Used in section 439.
- < Convert math glue to ordinary glue 906 > Used in section 904.
- < Convert *nucleus(q)* to an hlist and attach the sub/superscripts 928 > Used in section 902.
- < Convert string *s* into a new pseudo file 1751 > Used in section 1750.
- < Copy the tabskip glue between columns 969 > Used in section 965.
- < Copy the templates from node *cur_loop* into node *p* 968 > Used in section 967.
- < Copy the token list 492 > Used in section 491.
- < Create a character node *p* for *nucleus(q)*, possibly followed by a kern node for the italic correction, and set *delta* to the italic correction if a subscript is present 929 > Used in section 928.
- < Create a character node *q* for the next character, but set $q \leftarrow null$ if problems arise 1300 > Used in section 1299.
- < Create a new array element of type *t* with index *i* 1817 > Used in section 1816.
- < Create a new glue specification whose width is *cur_val*; scan for its stretch and shrink components 488 > Used in section 487.
- < Create a page insertion node with $subtype(r) = qi(n)$, and include the glue correction for box *n* in the current page state 1184 > Used in section 1183.
- < Create an active breakpoint representing the beginning of the paragraph 1038 > Used in section 1037.
- < Create and append a discretionary node as an alternative to the unhyphenated word, and continue to develop both branches until they become equivalent 1089 > Used in section 1088.
- < Create equal-width boxes *x* and *z* for the numerator and denominator, and compute the default amounts *shift_up* and *shift_down* by which they are displaced from the baseline 918 > Used in section 917.
- < Create link annotations for the current hbox if needed 730 > Used in section 729.
- < Create new active nodes for the best feasible breaks just found 1010 > Used in section 1009.
- < Create the *format.ident*, open the format file, and inform the user that dumping has begun 1506 > Used in section 1478.
- < Create thread for the current vbox if needed 739 > Used in section 738.
- < Current *mem* equivalent of glue parameter number *n* 242 > Used in sections 170 and 172.
- < Deactivate node *r* 1034 > Used in section 1025.
- < Declare ε -TeX procedures for expanding 1749, 1807, 1812, 1816 > Used in section 388.
- < Declare ε -TeX procedures for scanning 1679, 1769, 1778, 1783 > Used in section 435.

- < Declare ε -TeX procedures for token lists 1680, 1750 > Used in section 490.
- < Declare ε -TeX procedures for tracing and input 306, 1658, 1659, 1753, 1754, 1771, 1773, 1774, 1818, 1820, 1834, 1835, 1836, 1837, 1838 > Used in section 290.
- < Declare ε -TeX procedures for use by *main_control* 1653, 1676, 1692 > Used in section 989.
- < Declare action procedures for use by *main_control* 1219, 1223, 1225, 1226, 1227, 1230, 1236, 1237, 1240, 1245, 1246, 1251, 1255, 1260, 1262, 1267, 1269, 1271, 1272, 1275, 1277, 1279, 1281, 1286, 1289, 1293, 1295, 1299, 1303, 1305, 1307, 1311, 1312, 1314, 1318, 1327, 1331, 1335, 1336, 1339, 1341, 1348, 1350, 1352, 1357, 1367, 1370, 1376, 1387, 1446, 1451, 1455, 1464, 1469, 1478, 1526, 1621 > Used in section 1205.
- < Declare math construction procedures 908, 909, 910, 911, 912, 917, 923, 926, 930, 936 > Used in section 900.
- < Declare procedures for preprocessing hyphenation patterns 1119, 1123, 1124, 1128, 1132, 1134, 1135, 1141 > Used in section 1117.
- < Declare procedures needed for displaying the elements of mlists 865, 866, 868 > Used in section 197.
- < Declare procedures needed for expressions 1779, 1784 > Used in section 487.
- < Declare procedures needed in *do_extension* 1527, 1528, 1535, 1550, 1554, 1560, 1564, 1571, 1575, 1585, 1597 > Used in section 1526.
- < Declare procedures needed in *hlist_out*, *vlist_out* 1612, 1614, 1617, 1716, 1720 > Used in section 647.
- < Declare procedures needed in *pdf_hlist_out*, *pdf_vlist_out* 727, 772, 778, 785, 1562, 1627, 1632, 1633, 1634 > Used in section 729.
- < Declare procedures that need to be declared forward for pdfTeX 686, 689, 698, 699, 700, 703, 1543, 1553 > Used in section 190.
- < Declare procedures that scan font-related stuff 604, 605 > Used in section 435.
- < Declare procedures that scan restricted classes of integers 459, 460, 461, 462, 463, 1808 > Used in section 435.
- < Declare subprocedures for *after_math* 1741 > Used in section 1370.
- < Declare subprocedures for *init_math* 1730, 1735 > Used in section 1314.
- < Declare subprocedures for *line_break* 1000, 1003, 1051, 1070, 1117 > Used in section 989.
- < Declare subprocedures for *prefixed_command* 1391, 1405, 1412, 1419, 1420, 1421, 1422, 1423, 1433, 1441 > Used in section 1387.
- < Declare subprocedures for *scan_expr* 1790, 1794, 1796 > Used in section 1779.
- < Declare subprocedures for *var_delimiter* 883, 885, 886 > Used in section 880.
- < Declare the function called *do_marks* 1822 > Used in section 1152.
- < Declare the function called *fin_mlist* 1360 > Used in section 1350.
- < Declare the function called *open_fmt_file* 550 > Used in section 1479.
- < Declare the function called *reconstitute* 1081 > Used in section 1070.
- < Declare the procedure called *align_peek* 959 > Used in section 974.
- < Declare the procedure called *fire_up* 1187 > Used in section 1169.
- < Declare the procedure called *get_preamble_token* 956 > Used in section 948.
- < Declare the procedure called *handle_right_brace* 1244 > Used in section 1205.
- < Declare the procedure called *init_span* 961 > Used in section 960.
- < Declare the procedure called *insert_relax* 405 > Used in section 388.
- < Declare the procedure called *macro_call* 415 > Used in section 388.
- < Declare the procedure called *print_cmd_chr* 320 > Used in section 270.
- < Declare the procedure called *print_skip_param* 243 > Used in section 197.
- < Declare the procedure called *runaway* 328 > Used in section 137.
- < Declare the procedure called *show_token_list* 314 > Used in section 137.
- < Decry the invalid character and **goto** *restart* 368 > Used in section 366.
- < Delete $c - "0"$ tokens and **goto** *continue* 88 > Used in section 84.
- < Delete the page-insertion nodes 1194 > Used in section 1189.
- < Destroy the t nodes following q , and make r point to the following node 1057 > Used in section 1056.
- < Determine horizontal glue shrink setting, then **return** or **goto** *common_ending* 838 > Used in section 831.
- < Determine horizontal glue stretch setting, then **return** or **goto** *common_ending* 832 > Used in section 831.
- < Determine the displacement, d , of the left edge of the equation, with respect to the line size z , assuming that $l = false$ 1378 > Used in section 1375.

- ⟨Determine the shrink order 839⟩ Used in sections 838, 850, and 970.
- ⟨Determine the stretch order 833⟩ Used in sections 832, 847, and 970.
- ⟨Determine the value of *height*(*r*) and the appropriate glue setting; then **return** or **goto** *common_ending* 846⟩ Used in section 842.
- ⟨Determine the value of *width*(*r*) and the appropriate glue setting; then **return** or **goto** *common_ending* 831⟩ Used in section 821.
- ⟨Determine vertical glue shrink setting, then **return** or **goto** *common_ending* 850⟩ Used in section 846.
- ⟨Determine vertical glue stretch setting, then **return** or **goto** *common_ending* 847⟩ Used in section 846.
- ⟨Discard erroneous prefixes and **return** 1388⟩ Used in section 1387.
- ⟨Discard the prefixes **\long** and **\outer** if they are irrelevant 1389⟩ Used in section 1387.
- ⟨Dispense with trivial cases of void or bad boxes 1153⟩ Used in section 1152.
- ⟨Display μ rule spec_{*i*} for whatsit node created by pdfTeX 1598⟩ Used in sections 1600, 1600, and 1600.
- ⟨Display adjustment *p* 215⟩ Used in section 201.
- ⟨Display box *p* 202⟩ Used in section 201.
- ⟨Display choice node *p* 869⟩ Used in section 864.
- ⟨Display discretionary *p* 213⟩ Used in section 201.
- ⟨Display fraction noad *p* 871⟩ Used in section 864.
- ⟨Display glue *p* 207⟩ Used in section 201.
- ⟨Display if this box is never to be reversed 1701⟩ Used in section 202.
- ⟨Display insertion *p* 206⟩ Used in section 201.
- ⟨Display kern *p* 209⟩ Used in section 201.
- ⟨Display leaders *p* 208⟩ Used in section 207.
- ⟨Display ligature *p* 211⟩ Used in section 201.
- ⟨Display mark *p* 214⟩ Used in section 201.
- ⟨Display math node *p* 210⟩ Used in section 201.
- ⟨Display node *p* 201⟩ Used in section 200.
- ⟨Display normal noad *p* 870⟩ Used in section 864.
- ⟨Display penalty *p* 212⟩ Used in section 201.
- ⟨Display rule *p* 205⟩ Used in section 201.
- ⟨Display special fields of the unset node *p* 203⟩ Used in section 202.
- ⟨Display the current context 334⟩ Used in section 333.
- ⟨Display the insertion split cost 1186⟩ Used in section 1185.
- ⟨Display the page break cost 1181⟩ Used in section 1180.
- ⟨Display the token (*m*, *c*) 316⟩ Used in section 315.
- ⟨Display the value of *b* 528⟩ Used in section 524.
- ⟨Display the value of *glue_set*(*p*) 204⟩ Used in section 202.
- ⟨Display the whatsit node *p* 1600⟩ Used in section 201.
- ⟨Display token *p*, and **return** if there are problems 315⟩ Used in section 314.
- ⟨Do first-pass processing based on *type*(*q*); **goto** *done_with_noad* if a noad has been fully processed, **goto** *check_dimensions* if it has been translated into *new_hlist*(*q*), or **goto** *done_with_node* if a node has been fully processed 902⟩ Used in section 901.
- ⟨Do ligature or kern command, returning to *main_lig_loop* or *main_loop_wrapup* or *main_loop_move* 1216⟩ Used in section 1214.
- ⟨Do magic computation 342⟩ Used in section 314.
- ⟨Do some work that has been queued up for **\write** 1619⟩ Used in section 1617.
- ⟨Do typesetting the DVI commands in virtual character packet 726⟩ Used in section 725.
- ⟨Drop current token and complain that it was unmatched 1242⟩ Used in section 1240.
- ⟨Dump a couple more things and the closing check word 1504⟩ Used in section 1478.
- ⟨Dump constants for consistency check 1483⟩ Used in section 1478.
- ⟨Dump pdftex data 1502⟩ Used in section 1478.
- ⟨Dump regions 1 to 4 of *eqtb* 1491⟩ Used in section 1489.
- ⟨Dump regions 5 and 6 of *eqtb* 1492⟩ Used in section 1489.

- ⟨Dump the ε -TeX state 1651, 1755⟩ Used in section 1483.
- ⟨Dump the array info for internal font number k 1498⟩ Used in section 1496.
- ⟨Dump the dynamic memory 1487⟩ Used in section 1478.
- ⟨Dump the font information 1496⟩ Used in section 1478.
- ⟨Dump the hash table 1494⟩ Used in section 1489.
- ⟨Dump the hyphenation tables 1500⟩ Used in section 1478.
- ⟨Dump the string pool 1485⟩ Used in section 1478.
- ⟨Dump the table of equivalents 1489⟩ Used in section 1478.
- ⟨Either append the insertion node p after node q , and remove it from the current page, or delete $node(p)$ 1197⟩ Used in section 1195.
- ⟨Either insert the material specified by node p into the appropriate box, or hold it for the next page; also delete node p from the current page 1195⟩ Used in section 1189.
- ⟨Either process `\ifcase` or set b to the value of a boolean condition 527⟩ Used in section 524.
- ⟨Empty the last bytes out of `dvi_buf` 626⟩ Used in section 670.
- ⟨Enable ε -TeX, if requested 1645⟩ Used in section 1515.
- ⟨Ensure that box 255 is empty after output 1203⟩ Used in section 1201.
- ⟨Ensure that box 255 is empty before output 1190⟩ Used in section 1189.
- ⟨Ensure that $trie_max \geq h + 256$ 1129⟩ Used in section 1128.
- ⟨Enter a hyphenation exception 1114⟩ Used in section 1110.
- ⟨Enter all of the patterns into a linked trie, until coming to a right brace 1136⟩ Used in section 1135.
- ⟨Enter as many hyphenation exceptions as are listed, until coming to a right brace; then **return** 1110⟩
Used in section 1109.
- ⟨Enter `skip_blanks` state, emit a space 371⟩ Used in section 369.
- ⟨Error handling procedures 78, 81, 82, 93, 94, 95⟩ Used in section 4.
- ⟨Evaluate the current expression 1789⟩ Used in section 1780.
- ⟨Examine node p in the hlist, taking account of its effect on the dimensions of the new box, or moving it to the adjustment list; then advance p to the next node 823⟩ Used in section 821.
- ⟨Examine node p in the vlist, taking account of its effect on the dimensions of the new box; then advance p to the next node 843⟩ Used in section 842.
- ⟨Expand a nonmacro 391⟩ Used in section 388.
- ⟨Expand macros in the token list and make `link(def_ref)` point to the result 1615⟩ Used in section 1614.
- ⟨Expand the next part of the input 504⟩ Used in section 503.
- ⟨Expand the token after the next token 392⟩ Used in section 391.
- ⟨Explain that too many dead cycles have occurred in a row 1199⟩ Used in section 1187.
- ⟨Express astonishment that no number was here 472⟩ Used in section 470.
- ⟨Express consternation over the fact that no alignment is in progress 1304⟩ Used in section 1303.
- ⟨Express shock at the missing left brace; **goto found** 501⟩ Used in section 500.
- ⟨Feed the macro body and its parameters to the scanner 416⟩ Used in section 415.
- ⟨Fetch a box dimension 446⟩ Used in section 439.
- ⟨Fetch a character code from some table 440⟩ Used in section 439.
- ⟨Fetch a font dimension 451⟩ Used in section 439.
- ⟨Fetch a font integer 452⟩ Used in section 439.
- ⟨Fetch a penalties array element 1863⟩ Used in section 449.
- ⟨Fetch a register 453⟩ Used in section 439.
- ⟨Fetch a token list or font identifier, provided that $level = tok_val$ 441⟩ Used in section 439.
- ⟨Fetch an internal dimension and **goto attach_sign**, or fetch an internal integer 475⟩ Used in section 474.
- ⟨Fetch an item in the current node, if appropriate 450⟩ Used in section 439.
- ⟨Fetch something on the `page-so-far` 447⟩ Used in section 439.
- ⟨Fetch the `dead_cycles` or the `insert_penalties` 445⟩ Used in section 439.
- ⟨Fetch the `par_shape` size 449⟩ Used in section 439.
- ⟨Fetch the `prev_graf` 448⟩ Used in section 439.
- ⟨Fetch the `space_factor` or the `prev_depth` 444⟩ Used in section 439.

- ⟨Find an active node with fewest demerits 1048⟩ Used in section 1047.
- ⟨Find hyphen locations for the word in *hc*, or **return** 1098⟩ Used in section 1070.
- ⟨Find optimal breakpoints 1037⟩ Used in section 989.
- ⟨Find the best active node for the desired looseness 1049⟩ Used in section 1047.
- ⟨Find the best way to split the insertion, and change *type(r)* to *split_up* 1185⟩ Used in section 1183.
- ⟨Find the glue specification, *main.p*, for text spaces in the current font 1218⟩ Used in sections 1217 and 1219.
- ⟨Finish an alignment in a display 1382⟩ Used in section 986.
- ⟨Finish displayed math 1375⟩ Used in section 1370.
- ⟨Finish issuing a diagnostic message for an overfull or underfull hbox 837⟩ Used in section 821.
- ⟨Finish issuing a diagnostic message for an overfull or underfull vbox 849⟩ Used in section 842.
- ⟨Finish line, emit a **\par** 373⟩ Used in section 369.
- ⟨Finish line, emit a space 370⟩ Used in section 369.
- ⟨Finish line, **goto switch** 372⟩ Used in section 369.
- ⟨Finish math in text 1372⟩ Used in section 1370.
- ⟨Finish shipping 759⟩ Used in section 751.
- ⟨Finish stream of page/form contents 760⟩ Used in section 759.
- ⟨Finish the PDF file 794⟩ Used in section 1511.
- ⟨Finish the DVI file 670⟩ Used in section 1511.
- ⟨Finish the extensions 1623⟩ Used in section 1511.
- ⟨Finish the natural width computation 1732⟩ Used in section 1322.
- ⟨Finish the reversed hlist segment and **goto done** 1726⟩ Used in section 1725.
- ⟨Finish *hlist_out* for mixed direction typesetting 1712⟩ Used in sections 647 and 729.
- ⟨Fire up the user's output routine and **return** 1200⟩ Used in section 1187.
- ⟨Fix the reference count, if any, and negate *cur_val* if *negative* 456⟩ Used in section 439.
- ⟨Flush PDF mark lists 765⟩ Used in section 759.
- ⟨Flush resource lists 764⟩ Used in section 759.
- ⟨Flush the box from memory, showing statistics if requested 667⟩ Used in sections 666 and 750.
- ⟨Flush the prototype box 1740⟩ Used in section 1375.
- ⟨Flush *pdf_start_link_node*'s created by *append_link* 783⟩ Used in section 782.
- ⟨Forbidden cases detected in *main_control* 1224, 1274, 1287, 1320⟩ Used in section 1221.
- ⟨Generate ProcSet 768⟩ Used in section 762.
- ⟨Generate XObject resources 767⟩ Used in section 762.
- ⟨Generate a *down* or *right* command for *w* and **return** 637⟩ Used in section 634.
- ⟨Generate a *y0* or *z0* command in order to reuse a previous appearance of *w* 636⟩ Used in section 634.
- ⟨Generate all ε -TeX primitives 1646, 1654, 1660, 1663, 1666, 1669, 1672, 1681, 1683, 1686, 1689, 1694, 1698, 1744, 1756, 1759, 1767, 1775, 1798, 1802, 1806, 1858, 1861⟩ Used in section 1645.
- ⟨Generate array of annotations or beads in page 771⟩ Used in section 769.
- ⟨Generate font resources 766⟩ Used in section 762.
- ⟨Generate parent pages object 770⟩ Used in section 769.
- ⟨Get ready to compress the trie 1127⟩ Used in section 1141.
- ⟨Get ready to start line breaking 990, 1001, 1008, 1022⟩ Used in section 989.
- ⟨Get the first line of input and prepare to start 1515⟩ Used in section 1510.
- ⟨Get the next non-blank non-call token 432⟩ Used in sections 431, 467, 481, 529, 552, 604, 1221, 1766, 1781, and 1782.
- ⟨Get the next non-blank non-relax non-call token 430⟩ Used in sections 429, 1254, 1260, 1327, 1336, 1387, 1402, and 1446.
- ⟨Get the next non-blank non-sign token; set *negative* appropriately 467⟩ Used in sections 466, 474, and 487.
- ⟨Get the next token, suppressing expansion 380⟩ Used in section 379.
- ⟨Get user's advice and **return** 83⟩ Used in section 82.
- ⟨Give diagnostic information, if requested 1206⟩ Used in section 1205.
- ⟨Give improper **\hyphenation** error 1111⟩ Used in section 1110.
- ⟨Global variables 13, 20, 26, 30, 32, 39, 50, 54, 73, 76, 79, 96, 104, 110, 117, 133, 134, 135, 136, 142, 183, 191, 199, 231, 264, 271, 274, 275, 293, 308, 319, 323, 326, 327, 330, 331, 332, 355, 383, 389, 408, 413, 414, 436, 464, 473, 506, 515, 519,

- 538, 539, 546, 553, 558, 565, 575, 576, 581, 619, 622, 632, 643, 676, 680, 687, 691, 696, 701, 704, 708, 710, 723, 774, 809, 816, 817, 819, 827, 835, 858, 893, 898, 938, 944, 988, 995, 997, 999, 1002, 1007, 1013, 1021, 1046, 1067, 1075, 1080, 1082, 1096, 1101, 1118, 1122, 1125, 1146, 1155, 1157, 1164, 1207, 1250, 1442, 1457, 1475, 1481, 1509, 1520, 1523, 1541, 1545, 1548, 1555, 1557, 1568, 1581, 1625, 1630, 1637, 1649, 1657, 1702, 1747, 1770, 1811, 1813, 1832, 1839, 1855, 1856 } Used in section 4.
- <Go into display math mode 1321> Used in section 1314.
- <Go into ordinary math mode 1315> Used in sections 1314 and 1318.
- <Go through the preamble list, determining the column widths and changing the alignrecords to dummy unset boxes 975> Used in section 974.
- <Grow more variable-size memory and **goto restart** 144> Used in section 143.
- <Handle \readline and **goto done** 1758> Used in section 509.
- <Handle \unexpanded or \detokenize and **return** 1685> Used in section 491.
- <Handle a glue node for mixed direction typesetting 1696> Used in sections 653, 735, and 1723.
- <Handle a math node in *hlist_out* 1713> Used in sections 650 and 732.
- <Handle non-positive logarithm 121> Used in section 119.
- <Handle saved items and **goto done** 1860> Used in section 1286.
- <Handle situations involving spaces, braces, changes of state 369> Used in section 366.
- <If a line number class has ended, create new active nodes for the best feasible breaks in that class; then **return** if $r = last_active$, otherwise compute the new *line_width* 1009> Used in section 1003.
- <If all characters of the family fit relative to h , then **goto found**, otherwise **goto not_found** 1130> Used in section 1128.
- <If an alignment entry has just ended, take appropriate action 364> Used in section 363.
- <If an expanded code is present, reduce it and **goto start_cs** 377> Used in sections 376 and 378.
- <If dumping is not allowed, abort 1480> Used in section 1478.
- <If instruction cur_i is a kern with cur_c , attach the kern after q ; or if it is a ligature with cur_c , combine noads q and p appropriately; then **return** if the cursor has moved past a noad, or **goto restart** 927> Used in section 926.
- <If no hyphens were found, **return** 1077> Used in section 1070.
- <If node cur_p is a legal breakpoint, call *try_break*; then update the active widths by including the glue in *glue_ptr(cur_p)* 1042> Used in section 1040.
- <If node p is a legal breakpoint, check if this break is the best known, and **goto done** if p is null or if the page-so-far is already too full to accept more stuff 1147> Used in section 1145.
- <If node q is a style node, change the style and **goto delete_q**; otherwise if it is not a noad, put it into the hlist, advance q , and **goto done**; otherwise set s to the size of noad q , set t to the associated type (*ord_noad* .. *inner_noad*), and set pen to the associated penalty 935> Used in section 934.
- <If node r is of type *delta_node*, update *cur_active_width*, set *prev_r* and *prev_prev_r*, then **goto continue** 1006> Used in section 1003.
- <If the current list ends with a box node, delete it from the list and make *cur_box* point to it; otherwise set *cur_box* \leftarrow null 1256> Used in section 1255.
- <If the current page is empty and node p is to be deleted, **goto done1**; otherwise use node p to update the state of the current page; if this node is an insertion, **goto contribute**; otherwise if this node is not a legal breakpoint, **goto contribute** or *update_heights*; otherwise set pi to the penalty associated with this breakpoint 1175> Used in section 1172.
- <If the cursor is immediately followed by the right boundary, **goto reswitch**; if it's followed by an invalid character, **goto big_switch**; otherwise move the cursor one step to the right and **goto main_lig_loop** 1211> Used in section 1209.
- <If the next character is a parameter number, make *cur_tok* a *match* token; but if it is a left brace, store 'left_brace, end_match', set *hash_brace*, and **goto done** 502> Used in section 500.
- <If the preamble list has been traversed, check that the row has ended 966> Used in section 965.
- <If the right-hand side is a token parameter or token register, finish the assignment and **goto done** 1403> Used in section 1402.

- <If the string *hyph_word*[*h*] is less than *hc*[1 .. *hn*], **goto** *not_found*; but if the two strings are equal, set *hyf* to the hyphen positions and **goto** *found* 1106> Used in section 1105.
- <If the string *hyph_word*[*h*] is less than or equal to *s*, interchange (*hyph_word*[*h*], *hyph_list*[*h*]) with (*s*, *p*) 1116> Used in section 1115.
- <If there's a ligature or kern at the cursor position, update the data structures, possibly advancing *j*; continue until the cursor moves 1084> Used in section 1081.
- <If there's a ligature/kern command relevant to *cur_l* and *cur_r*, adjust the text appropriately; exit to *main_loop_wrapup* 1214> Used in section 1209.
- <If this font has already been loaded, set *f* to the internal font number and **goto** *common_ending* 1436> Used in section 1433.
- <If this *sup_mark* starts an expanded character like $\sim A$ or $\sim df$, then **goto** *reswitch*, otherwise set *state* \leftarrow *mid_line* 374> Used in section 366.
- <If *tmp_k1* is not null then append that kern 1215> Used in sections 1209 and 1214.
- <Ignore the fraction operation and complain about this ambiguous case 1359> Used in section 1357.
- <Implement `\closeout` 1531> Used in section 1526.
- <Implement `\immediate` 1620> Used in section 1526.
- <Implement `\openout` 1529> Used in section 1526.
- <Implement `\pdfannot` 1556> Used in section 1526.
- <Implement `\pdfcatalog` 1577> Used in section 1526.
- <Implement `\pdfcolorstack` 1537> Used in section 1526.
- <Implement `\pdfdest` 1563> Used in section 1526.
- <Implement `\pdfendlink` 1559> Used in section 1526.
- <Implement `\pdfendthread` 1567> Used in section 1526.
- <Implement `\pdffakespace` 1594> Used in section 1526.
- <Implement `\pdffontattr` 1587> Used in section 1526.
- <Implement `\pdffontexpand` 1533> Used in section 1526.
- <Implement `\pdfglyptounicode` 1590> Used in section 1526.
- <Implement `\pdfincludechars` 1586> Used in section 1526.
- <Implement `\pdfinfo` 1576> Used in section 1526.
- <Implement `\pdfinterwordspaceoff` 1593> Used in section 1526.
- <Implement `\pdfinterwordspaceon` 1592> Used in section 1526.
- <Implement `\pdfliteral` 1536> Used in section 1526.
- <Implement `\pdfmapfile` 1588> Used in section 1526.
- <Implement `\pdfmapline` 1589> Used in section 1526.
- <Implement `\pdfnames` 1578> Used in section 1526.
- <Implement `\pdfnobuiltintounicode` 1591> Used in section 1526.
- <Implement `\pdfobj` 1542> Used in section 1526.
- <Implement `\pdfoutline` 1561> Used in section 1526.
- <Implement `\pdfprimitive` 394> Used in section 391.
- <Implement `\pdfrefobj` 1544> Used in section 1526.
- <Implement `\pdfrefxform` 1547> Used in section 1526.
- <Implement `\pdfrefximage` 1552> Used in section 1526.
- <Implement `\pdfresettimer` 1584> Used in section 1526.
- <Implement `\pdfrestore` 1540> Used in section 1526.
- <Implement `\pdfrunninglinkoff` 1595> Used in section 1526.
- <Implement `\pdfrunninglinkon` 1596> Used in section 1526.
- <Implement `\pdfsavepos` 1574> Used in section 1526.
- <Implement `\pdfsave` 1539> Used in section 1526.
- <Implement `\pdfsetmatrix` 1538> Used in section 1526.
- <Implement `\pdfsetrandomseed` 1583> Used in section 1526.
- <Implement `\pdfsnaprefpoint` 1570> Used in section 1526.
- <Implement `\pdfsnapycomp` 1573> Used in section 1526.

- <Implement `\pdfsnappy` 1572> Used in section 1526.
- <Implement `\pdfstartlink` 1558> Used in section 1526.
- <Implement `\pdfstartthread` 1566> Used in section 1526.
- <Implement `\pdfthread` 1565> Used in section 1526.
- <Implement `\pdftrailerid` 1580> Used in section 1526.
- <Implement `\pdftrailer` 1579> Used in section 1526.
- <Implement `\pdfxform` 1546> Used in section 1526.
- <Implement `\pdfximage` 1551> Used in section 1526.
- <Implement `\setlanguage` 1622> Used in section 1526.
- <Implement `\special` 1532> Used in section 1526.
- <Implement `\write` 1530> Used in section 1526.
- <Incorporate a whatsit node into a vbox 1603> Used in section 843.
- <Incorporate a whatsit node into an hbox 1604> Used in section 823.
- <Incorporate box dimensions into the dimensions of the hbox that will contain it 825> Used in section 823.
- <Incorporate box dimensions into the dimensions of the vbox that will contain it 844> Used in section 843.
- <Incorporate character dimensions into the dimensions of the hbox that will contain it, then move to the next node 826> Used in section 823.
- <Incorporate glue into the horizontal totals 830> Used in section 823.
- <Incorporate glue into the vertical totals 845> Used in section 843.
- <Increase the number of parameters in the last font 607> Used in section 605.
- <Increase k until x can be multiplied by a factor of 2^{-k} , and adjust y accordingly 120> Used in section 119.
- <Initialize additional fields of the first active node 1842> Used in section 1038.
- <Initialize for hyphenating a paragraph 1066> Used in section 1037.
- <Initialize table entries (done by INITEX only) 182, 240, 246, 250, 258, 268, 277, 578, 672, 1062, 1121, 1126, 1392, 1477, 1613, 1650, 1815, 1851> Used in section 8.
- <Initialize the LR stack 1707> Used in sections 821, 1711, and 1731.
- <Initialize the current page, insert the `\topskip` glue ahead of p , and **goto** *continue* 1176> Used in section 1175.
- <Initialize the input routines 353> Used in section 1515.
- <Initialize the output routines 55, 61, 554, 559> Used in section 1510.
- <Initialize the print *selector* based on *interaction* 75> Used in sections 1441 and 1515.
- <Initialize the special list heads and constant nodes 964, 971, 994, 1156, 1163> Used in section 182.
- <Initialize variables as *pdf.ship_out* begins 752> Used in section 751.
- <Initialize variables as *ship_out* begins 645> Used in section 668.
- <Initialize variables for PDF output 792> Used in section 750.
- <Initialize variables for ε -TeX compatibility mode 1809> Used in sections 1650 and 1652.
- <Initialize variables for ε -TeX extended mode 1810> Used in sections 1645 and 1652.
- <Initialize whatever TeX might access 8> Used in section 4.
- <Initialize *hlist_out* for mixed direction typesetting 1711> Used in sections 647 and 729.
- <Initiate input from new pseudo file 1752> Used in section 1750.
- <Initiate or terminate input from a file 404> Used in section 391.
- <Initiate the construction of an hbox or vbox, then **return** 1259> Used in section 1255.
- <Input and store tokens from the next line of the file 509> Used in section 508.
- <Input for `\read` from the terminal 510> Used in section 509.
- <Input from external file, **goto** *restart* if no input found 365> Used in section 363.
- <Input from token list, **goto** *restart* if end of list or if a parameter needs to be expanded 379> Used in section 363.
- <Input the first line of *read_file*[m] 511> Used in section 509.
- <Input the next line of *read_file*[m] 512> Used in section 509.
- <Insert LR nodes at the beginning of the current line and adjust the LR stack based on LR nodes in this line 1704> Used in section 1054.
- <Insert LR nodes at the end of the current line 1706> Used in section 1054.

- ⟨Insert a delta node to prepare for breaks at *cur_p* 1017⟩ Used in section 1010.
- ⟨Insert a delta node to prepare for the next active node 1018⟩ Used in section 1010.
- ⟨Insert a dummy node to be sub/superscripted 1353⟩ Used in section 1352.
- ⟨Insert a new active node from *best_place*[*fit_class*] to *cur_p* 1019⟩ Used in section 1010.
- ⟨Insert a new control sequence after *p*, then make *p* point to it 279⟩ Used in section 278.
- ⟨Insert a new pattern into the linked trie 1138⟩ Used in section 1136.
- ⟨Insert a new primitive after *p*, then make *p* point to it 282⟩ Used in section 281.
- ⟨Insert a new trie node between *q* and *p*, and make *p* point to it 1139⟩ Used in sections 1138, 1852, and 1853.
- ⟨Insert a token containing *frozen_endv* 401⟩ Used in section 388.
- ⟨Insert a token saved by `\afterassignment`, if any 1445⟩ Used in section 1387.
- ⟨Insert glue for *split_top_skip* and set $p \leftarrow \text{null}$ 1144⟩ Used in section 1143.
- ⟨Insert hyphens as specified in *hyph_list*[*h*] 1107⟩ Used in section 1106.
- ⟨Insert macro parameter and **goto** *restart* 381⟩ Used in section 379.
- ⟨Insert the appropriate mark text into the scanner 412⟩ Used in section 391.
- ⟨Insert the current list into its environment 986⟩ Used in section 974.
- ⟨Insert the pair (*s*, *p*) into the exception table 1115⟩ Used in section 1114.
- ⟨Insert the $\langle v_j \rangle$ template and **goto** *restart* 963⟩ Used in section 364.
- ⟨Insert token *p* into TeX’s input 348⟩ Used in section 304.
- ⟨Interpret code *c* and **return** if done 84⟩ Used in section 83.
- ⟨Introduce new material from the terminal and **return** 87⟩ Used in section 84.
- ⟨Issue an error message if $cur_val = fmem_ptr$ 606⟩ Used in section 605.
- ⟨Justify the line ending at breakpoint *cur_p*, and append it to the current vertical list, together with associated penalties and other insertions 1054⟩ Used in section 1051.
- ⟨Labels in the outer block 6⟩ Used in section 4.
- ⟨Last-minute procedures 1511, 1513, 1514, 1516⟩ Used in section 1508.
- ⟨Lengthen the preamble periodically 967⟩ Used in section 966.
- ⟨Let *cur_h* be the position of the first box, and set $leader_wd + lx$ to the spacing between corresponding parts of boxes 655⟩ Used in sections 654 and 736.
- ⟨Let *cur_v* be the position of the first box, and set $leader_ht + lx$ to the spacing between corresponding parts of boxes 664⟩ Used in sections 663 and 745.
- ⟨Let *d* be the natural width of node *p*; if the node is “visible,” **goto** *found*; if the node is glue that stretches or shrinks, set $v \leftarrow max_dimen$ 1323⟩ Used in section 1322.
- ⟨Let *d* be the natural width of this glue; if stretching or shrinking, set $v \leftarrow max_dimen$; **goto** *found* in the case of leaders 1324⟩ Used in section 1323.
- ⟨Let *d* be the width of the whatsit *p* 1605⟩ Used in section 1323.
- ⟨Let *j* be the prototype box for the display 1737⟩ Used in section 1731.
- ⟨Let *n* be the largest legal code value, based on *cur_chr* 1409⟩ Used in section 1408.
- ⟨Link node *p* into the current page and **goto** *done* 1173⟩ Used in section 1172.
- ⟨Local variables for dimension calculations 476⟩ Used in section 474.
- ⟨Local variables for finishing a displayed formula 1374, 1738⟩ Used in section 1370.
- ⟨Local variables for formatting calculations 337⟩ Used in section 333.
- ⟨Local variables for hyphenation 1076, 1087, 1097, 1104⟩ Used in section 1070.
- ⟨Local variables for initialization 19, 181, 1102⟩ Used in section 4.
- ⟨Local variables for line breaking 1036, 1068⟩ Used in section 989.
- ⟨Look ahead for another character, or leave *lig_stack* empty if there’s none there 1213⟩ Used in section 1209.
- ⟨Look at all the marks in nodes before the break, and set the final link to *null* at the break 1154⟩ Used in section 1152.
- ⟨Look at the list of characters starting with *x* in font *g*; set *f* and *c* whenever a better character is found; **goto** *found* as soon as a large enough variant is encountered 882⟩ Used in section 881.
- ⟨Look at the other stack entries until deciding what sort of DVI command to generate; **goto** *found* if node *p* is a “hit” 638⟩ Used in section 634.

- ⟨Look at the variants of (z, x) ; set f and c whenever a better character is found; **goto** *found* as soon as a large enough variant is encountered 881⟩ Used in section 880.
- ⟨Look for parameter number or ## 505⟩ Used in section 503.
- ⟨Look for the word $hc[1 \dots hn]$ in the exception table, and **goto** *found* (with *hyf* containing the hyphens) if an entry is found 1105⟩ Used in section 1098.
- ⟨Look up the characters of list n in the hash table, and set *cur_cs* 1765⟩ Used in section 1764.
- ⟨Look up the characters of list r in the hash table, and set *cur_cs* 400⟩ Used in section 398.
- ⟨Make a copy of node p in node r 223⟩ Used in section 222.
- ⟨Make a ligature node, if *ligature_present*; insert a null discretionary, if appropriate 1210⟩ Used in section 1209.
- ⟨Make a partial copy of the whatsit node p and make r point to it; set *words* to the number of initial words not yet copied 1601⟩ Used in sections 224 and 1730.
- ⟨Make a second pass over the mlist, removing all noads and inserting the proper spacing and penalties 934⟩ Used in section 900.
- ⟨Make final adjustments and **goto** *done* 603⟩ Used in section 588.
- ⟨Make node p look like a *char_node* and **goto** *reswitch* 824⟩ Used in sections 650, 732, 823, and 1323.
- ⟨Make sure that f is in the proper range 1787⟩ Used in section 1780.
- ⟨Make sure that *page_max_depth* is not exceeded 1178⟩ Used in section 1172.
- ⟨Make sure that pi is in the proper range 1005⟩ Used in section 1003.
- ⟨Make the contribution list empty by setting its tail to *contrib_head* 1170⟩ Used in section 1169.
- ⟨Make the first 256 strings 48⟩ Used in section 47.
- ⟨Make the height of box y equal to h 913⟩ Used in section 912.
- ⟨Make the running dimensions in rule q extend to the boundaries of the alignment 980⟩ Used in section 979.
- ⟨Make the unset node r into a *vlist_node* of height w , setting the glue as if the height were t 985⟩ Used in section 982.
- ⟨Make the unset node r into an *hlist_node* of width w , setting the glue as if the width were t 984⟩ Used in section 982.
- ⟨Make variable b point to a box for (f, c) 884⟩ Used in section 880.
- ⟨Manufacture a control sequence name 398⟩ Used in section 391.
- ⟨Math-only cases in non-math modes, or vice versa 1222⟩ Used in section 1221.
- ⟨Merge the widths in the span nodes of q with those of p , destroying the span nodes of q 977⟩ Used in section 975.
- ⟨Modify the end of the line to reflect the nature of the break and to include **\rightskip**; also set the proper value of *disc_break* 1055⟩ Used in section 1054.
- ⟨Modify the glue specification in *main_p* according to the space factor 1220⟩ Used in section 1219.
- ⟨Move down or output leaders 662⟩ Used in section 659.
- ⟨Move down without outputting leaders 1635⟩ Used in section 1634.
- ⟨Move node p to the current page; if it is time for a page break, put the nodes following the break back onto the contribution list, and **return** to the user's output routine if there is one 1172⟩ Used in section 1169.
- ⟨Move node p to the new list and go to the next node; or **goto** *done* if the end of the reflected segment has been reached 1721⟩ Used in section 1720.
- ⟨Move pointer s to the end of the current list, and set *replace_count*(r) appropriately 1093⟩ Used in section 1089.
- ⟨Move right or output leaders 653⟩ Used in section 650.
- ⟨Move the characters of a ligature node to hu and hc ; but **goto** *done3* if they are not all letters 1073⟩ Used in section 1072.
- ⟨Move the cursor past a pseudo-ligature, then **goto** *main_loop_lookahead* or *main_lig_loop* 1212⟩ Used in section 1209.
- ⟨Move the data into *trie* 1133⟩ Used in section 1141.
- ⟨Move the non-*char_node* p to the new list 1722⟩ Used in section 1721.
- ⟨Move to next line of file, or **goto** *restart* if there is no next line, or **return** if a **\read** line has finished 382⟩ Used in section 365.
- ⟨Negate a boolean conditional and **goto** *reswitch* 1762⟩ Used in section 391.

- ⟨Negate all three glue components of *cur_val* 457⟩ Used in sections 456 and 1777.
- ⟨Nullify *width(q)* and the tabskip glue following this column 976⟩ Used in section 975.
- ⟨Numbered cases for *debug_help* 1517⟩ Used in section 1516.
- ⟨Open *tfm_file* for input 589⟩ Used in section 588.
- ⟨Open *vf_file*, return if not found 713⟩ Used in section 712.
- ⟨Other local variables for *try_break* 1004, 1841⟩ Used in section 1003.
- ⟨Output PDF outline entries 789⟩ Used in section 788.
- ⟨Output a Form node in a hlist 1644⟩ Used in section 1642.
- ⟨Output a Form node in a vlist 1641⟩ Used in section 1636.
- ⟨Output a Image node in a hlist 1643⟩ Used in section 1642.
- ⟨Output a Image node in a vlist 1640⟩ Used in section 1636.
- ⟨Output a box in a vlist 660⟩ Used in section 659.
- ⟨Output a box in an hlist 651⟩ Used in section 650.
- ⟨Output a leader box at *cur_h*, then advance *cur_h* by *leader_wd + lx* 656⟩ Used in section 654.
- ⟨Output a leader box at *cur_v*, then advance *cur_v* by *leader_ht + lx* 665⟩ Used in section 663.
- ⟨Output a rule in a vlist, **goto** *next_p* 661⟩ Used in section 659.
- ⟨Output a rule in an hlist 652⟩ Used in section 650.
- ⟨Output article threads 790⟩ Used in section 794.
- ⟨Output fonts definition 799⟩ Used in section 794.
- ⟨Output leaders in a vlist, **goto** *fin_rule* if a rule or to *next_p* if done 663⟩ Used in section 662.
- ⟨Output leaders in an hlist, **goto** *fin_rule* if a rule or to *next_p* if done 654⟩ Used in section 653.
- ⟨Output name tree 802⟩ Used in section 794.
- ⟨Output node *p* for *hlist_out* and move to the next node, maintaining the condition *cur_v = base_line* 648⟩
Used in section 647.
- ⟨Output node *p* for *pdf_hlist_out* and move to the next node, maintaining the condition *cur_v = base_line* 731⟩
Used in section 729.
- ⟨Output node *p* for *pdf_vlist_out* and move to the next node, maintaining the condition *cur_h = left_edge* 740⟩
Used in section 738.
- ⟨Output node *p* for *vlist_out* and move to the next node, maintaining the condition *cur_h = left_edge* 658⟩
Used in section 657.
- ⟨Output outlines 788⟩ Used in section 794.
- ⟨Output pages tree 800⟩ Used in section 794.
- ⟨Output statistics about this job 1512⟩ Used in section 1511.
- ⟨Output the catalog object 804⟩ Used in section 794.
- ⟨Output the cross-reference stream dictionary 812⟩ Used in section 794.
- ⟨Output the current Pages object in this level 801⟩ Used in section 800.
- ⟨Output the current node in this level 803⟩ Used in section 802.
- ⟨Output the font definitions for all fonts that were used 671⟩ Used in section 670.
- ⟨Output the font name whose internal number is *f* 630⟩ Used in section 629.
- ⟨Output the non-*char_node* *p* for *hlist_out* and move to the next node 650⟩ Used in section 648.
- ⟨Output the non-*char_node* *p* for *pdf_hlist_out* and move to the next node 732⟩ Used in section 731.
- ⟨Output the non-*char_node* *p* for *pdf_vlist_out* 741⟩ Used in section 740.
- ⟨Output the non-*char_node* *p* for *vlist_out* 659⟩ Used in section 658.
- ⟨Output the trailer 813⟩ Used in section 794.
- ⟨Output the whatsit node *p* in a vlist 1610⟩ Used in section 659.
- ⟨Output the whatsit node *p* in an hlist 1611⟩ Used in section 650.
- ⟨Output the whatsit node *p* in *pdf_hlist_out* 1642⟩ Used in section 732.
- ⟨Output the whatsit node *p* in *pdf_vlist_out* 1636⟩ Used in section 741.
- ⟨Output the *obj_tab* 811⟩ Used in section 794.
- ⟨Pack all stored *hyph_codes* 1854⟩ Used in section 1141.
- ⟨Pack the family into *trie* relative to *h* 1131⟩ Used in section 1128.
- ⟨Package an unset box for the current column and record its width 970⟩ Used in section 965.

- ⟨Package the display line 1743⟩ Used in section 1741.
- ⟨Package the preamble list, to determine the actual tabskip glue amounts, and let p point to this prototype box 978⟩ Used in section 974.
- ⟨Perform computations for last line and **goto found** 1843⟩ Used in section 1026.
- ⟨Perform the default output routine 1198⟩ Used in section 1187.
- ⟨Pontificate about improper alignment in display 1383⟩ Used in section 1382.
- ⟨Pop the condition stack 522⟩ Used in sections 524, 526, 535, and 536.
- ⟨Pop the expression stack and **goto found** 1786⟩ Used in section 1780.
- ⟨Prepare all the boxes involved in insertions to act as queues 1193⟩ Used in section 1189.
- ⟨Prepare for display after a non-empty paragraph 1731⟩ Used in section 1322.
- ⟨Prepare for display after an empty paragraph 1729⟩ Used in section 1321.
- ⟨Prepare to deactivate node r , and **goto deactivate** unless there is a reason to consider lines of text from r to cur_p 1028⟩ Used in section 1025.
- ⟨Prepare to insert a token that matches cur_group , and print what it is 1241⟩ Used in section 1240.
- ⟨Prepare to move a box or rule node to the current page, then **goto contribute** 1177⟩ Used in section 1175.
- ⟨Prepare to move whatsit p to the current page, then **goto contribute** 1608⟩ Used in section 1175.
- ⟨Print a short indication of the contents of node p 193⟩ Used in sections 192 and 674.
- ⟨Print a symbolic description of the new break node 1020⟩ Used in section 1019.
- ⟨Print a symbolic description of this feasible break 1030⟩ Used in section 1029.
- ⟨Print additional data in the new active node 1849⟩ Used in section 1020.
- ⟨Print additional resources 763⟩ Used in section 762.
- ⟨Print either ‘definition’ or ‘use’ or ‘preamble’ or ‘text’, and insert tokens that should lead to recovery 361⟩ Used in section 360.
- ⟨Print location of current line 335⟩ Used in section 334.
- ⟨Print newly busy locations 189⟩ Used in section 185.
- ⟨Print string s as an error message 1459⟩ Used in section 1455.
- ⟨Print string s on the terminal 1456⟩ Used in section 1455.
- ⟨Print the CreationDate key 807⟩ Used in section 805.
- ⟨Print the ModDate key 808⟩ Used in section 805.
- ⟨Print the Producer key 806⟩ Used in section 805.
- ⟨Print the banner line, including the date and time 562⟩ Used in section 560.
- ⟨Print the help information and **goto continue** 89⟩ Used in section 84.
- ⟨Print the list between $printed_node$ and cur_p , then set $printed_node \leftarrow cur_p$ 1031⟩ Used in section 1030.
- ⟨Print the menu of available options 85⟩ Used in section 84.
- ⟨Print the result of command c 498⟩ Used in section 496.
- ⟨Print two lines using the tricky pseudoprinted information 339⟩ Used in section 334.
- ⟨Print type of token list 336⟩ Used in section 334.
- ⟨Process an active-character control sequence and set $state \leftarrow mid_line$ 375⟩ Used in section 366.
- ⟨Process an expression and **return** 1777⟩ Used in section 450.
- ⟨Process node-or-noad q as much as possible in preparation for the second pass of $mlist_to_hlist$, then move to the next item in the mlist 901⟩ Used in section 900.
- ⟨Process the font definitions 715⟩ Used in section 712.
- ⟨Process the preamble 714⟩ Used in section 712.
- ⟨Process whatsit p in $vert_break$ loop, **goto not_found** 1609⟩ Used in section 1148.
- ⟨Prune the current list, if necessary, until it contains only $char_node$, $kern_node$, $hlist_node$, $vlist_node$, $rule_node$, and $ligature_node$ items; set n to the length of the list, and set q to the list’s tail 1297⟩ Used in section 1295.
- ⟨Prune unwanted nodes at the beginning of the next line 1053⟩ Used in section 1051.
- ⟨Pseudoprint the line 340⟩ Used in section 334.
- ⟨Pseudoprint the token list 341⟩ Used in section 334.
- ⟨Push the condition stack 521⟩ Used in section 524.
- ⟨Push the expression stack and **goto restart** 1785⟩ Used in section 1782.

- < Put each of TeX's primitives into the hash table 244, 248, 256, 266, 287, 356, 402, 410, 437, 442, 494, 513, 517, 579, 954, 1158, 1228, 1234, 1247, 1264, 1283, 1290, 1317, 1332, 1345, 1354, 1364, 1384, 1395, 1398, 1406, 1426, 1430, 1438, 1448, 1453, 1462, 1467, 1522 > Used in section 1514.
- < Put help message on the transcript file 90 > Used in section 82.
- < Put the characters $hu[i + 1 \dots]$ into $post_break(r)$, appending to this list and to $major_tail$ until synchronization has been achieved 1091 > Used in section 1089.
- < Put the characters $hu[l \dots i]$ and a hyphen into $pre_break(r)$ 1090 > Used in section 1089.
- < Put the fraction into a box with its delimiters, and make $new_hlist(q)$ point to it 922 > Used in section 917.
- < Put the $\backslash leftskip$ glue at the left and detach this line 1061 > Used in section 1054.
- < Put the optimal current page into box 255, update $first_mark$ and bot_mark , append insertions to their boxes, and put the remaining nodes back on the contribution list 1189 > Used in section 1187.
- < Put the (positive) 'at' size into s 1435 > Used in section 1434.
- < Put the $\backslash rightskip$ glue after node q 1060 > Used in section 1055.
- < Read and check the font data; *abort* if the TFM file is malformed; if there's no room for this font, say so and **goto** *done*; otherwise $incr(font_ptr)$ and **goto** *done* 588 > Used in section 586.
- < Read box dimensions 598 > Used in section 588.
- < Read character data 595 > Used in section 588.
- < Read extensible character recipes 601 > Used in section 588.
- < Read font parameters 602 > Used in section 588.
- < Read ligature/kern program 600 > Used in section 588.
- < Read next line of file into $buffer$, or **goto** *restart* if the file has ended 384 > Used in section 382.
- < Read one string, but return *false* if the string memory space is getting too tight for comfort 52 > Used in section 51.
- < Read the first line of the new file 564 > Used in section 563.
- < Read the other strings from the TEX.POOL file and return *true*, or give an error message and return *false* 51 > Used in section 47.
- < Read the TFM header 594 > Used in section 588.
- < Read the TFM size fields 591 > Used in section 588.
- < Readjust the height and depth of cur_box , for $\backslash vtop$ 1263 > Used in section 1262.
- < Reconstitute nodes for the hyphenated word, inserting discretionary hyphens 1088 > Used in section 1078.
- < Record a new feasible break 1029 > Used in section 1025.
- < Recover from an unbalanced output routine 1202 > Used in section 1201.
- < Recover from an unbalanced write command 1616 > Used in section 1615.
- < Recycle node p 1174 > Used in section 1172.
- < Reduce to the case that $a, c \geq 0$, $b, d > 0$ 123 > Used in section 122.
- < Reduce to the case that $f \geq 0$ and $q > 0$ 115 > Used in section 114.
- < Remove the last box, unless it's part of a discretionary 1257 > Used in section 1256.
- < Replace nodes $ha \dots hb$ by a sequence of nodes that includes the discretionary hyphens 1078 > Used in section 1070.
- < Replace the tail of the list by p 1363 > Used in section 1362.
- < Replace z by z' and compute α, β 599 > Used in section 598.
- < Report LR problems 1710 > Used in sections 1709 and 1727.
- < Report a runaway argument and abort 422 > Used in sections 418 and 425.
- < Report a tight hbox and **goto** *common_ending*, if this box is sufficiently bad 841 > Used in section 838.
- < Report a tight vbox and **goto** *common_ending*, if this box is sufficiently bad 852 > Used in section 850.
- < Report an extra right brace and **goto** *continue* 421 > Used in section 418.
- < Report an improper use of the macro and abort 424 > Used in section 423.
- < Report an overfull hbox and **goto** *common_ending*, if this box is sufficiently bad 840 > Used in section 838.
- < Report an overfull vbox and **goto** *common_ending*, if this box is sufficiently bad 851 > Used in section 850.
- < Report an underfull hbox and **goto** *common_ending*, if this box is sufficiently bad 834 > Used in section 832.
- < Report an underfull vbox and **goto** *common_ending*, if this box is sufficiently bad 848 > Used in section 847.
- < Report overflow of the input buffer, and abort 35 > Used in sections 31 and 1753.

- ⟨Report that an invalid delimiter code is being changed to null; set $cur_val \leftarrow 0$ 1337⟩ Used in section 1336.
- ⟨Report that the font won't be loaded 587⟩ Used in section 586.
- ⟨Report that this dimension is out of range 486⟩ Used in section 474.
- ⟨Reset PDF mark lists 754⟩ Used in section 752.
- ⟨Reset resource lists 753⟩ Used in sections 752 and 775.
- ⟨Reset cur_tok for unexpandable primitives, goto restart 395⟩ Used in sections 439 and 466.
- ⟨Restore resource lists 777⟩ Used in section 775.
- ⟨Resume the page builder after an output routine has come to an end 1201⟩ Used in section 1276.
- ⟨Retrieve the prototype box 1739⟩ Used in sections 1370 and 1370.
- ⟨Reverse an hlist segment and **goto** *reswitch* 1719⟩ Used in section 1714.
- ⟨Reverse the complete hlist and set the subtype to *reversed* 1718⟩ Used in section 1711.
- ⟨Reverse the linked list of Page and Pages objects 798⟩ Used in section 794.
- ⟨Reverse the links of the relevant passive nodes, setting cur_p to the first breakpoint 1052⟩ Used in section 1051.
- ⟨Save current position in DVI mode 1618⟩ Used in section 1617.
- ⟨Save current position to $pdf_last_x_pos$, $pdf_last_y_pos$ 1638⟩ Used in sections 1636 and 1642.
- ⟨Save current position to pdf_snapx_refpos , pdf_snapy_refpos 1639⟩ Used in sections 1636 and 1642.
- ⟨Save resource lists 776⟩ Used in section 775.
- ⟨Scan a control sequence and set $state \leftarrow skip_blanks$ or mid_line 376⟩ Used in section 366.
- ⟨Scan a factor f of type o or start a subexpression 1782⟩ Used in section 1780.
- ⟨Scan a numeric constant 470⟩ Used in section 466.
- ⟨Scan a parameter until its delimiter string has been found; or, if $s = null$, simply scan the delimiter string 418⟩ Used in section 417.
- ⟨Scan a subformula enclosed in braces and **return** 1329⟩ Used in section 1327.
- ⟨Scan ahead in the buffer until finding a nonletter; if an expanded code is encountered, reduce it and **goto** *start.cs*; otherwise if a multiletter control sequence is found, adjust cur_cs and loc , and **goto** *found* 378⟩ Used in section 376.
- ⟨Scan an alphabetic character code into cur_val 468⟩ Used in section 466.
- ⟨Scan an optional space 469⟩ Used in sections 468, 474, 481, 705, 1376, 1542, 1554, 1554, 1556, and 1563.
- ⟨Scan and build the body of the token list; **goto** *found* when finished 503⟩ Used in section 499.
- ⟨Scan and build the parameter part of the macro definition 500⟩ Used in section 499.
- ⟨Scan and evaluate an expression e of type l 1780⟩ Used in section 1779.
- ⟨Scan decimal fraction 478⟩ Used in section 474.
- ⟨Scan file name in the buffer 557⟩ Used in section 556.
- ⟨Scan for all other units and adjust cur_val and f accordingly; **goto** *done* in the case of scaled points 484⟩ Used in section 479.
- ⟨Scan for **fil** units; **goto** *attach_fraction* if found 480⟩ Used in section 479.
- ⟨Scan for **mu** units and **goto** *attach_fraction* 482⟩ Used in section 479.
- ⟨Scan for units that are internal dimensions; **goto** *attach_sign* with cur_val set if found 481⟩ Used in section 479.
- ⟨Scan preamble text until cur_cmd is *tab_mark* or *car_ret*, looking for changes in the tabskip glue; append an alignrecord to the preamble list 953⟩ Used in section 951.
- ⟨Scan the argument for command c 497⟩ Used in section 496.
- ⟨Scan the font size specification 1434⟩ Used in section 1433.
- ⟨Scan the next operator and set o 1781⟩ Used in section 1780.
- ⟨Scan the parameters and make $link(r)$ point to the macro body; but **return** if an illegal $\backslash par$ is detected 417⟩ Used in section 415.
- ⟨Scan the preamble and record it in the *preamble* list 951⟩ Used in section 948.
- ⟨Scan the template $\langle u_j \rangle$, putting the resulting token list in *hold_head* 957⟩ Used in section 953.
- ⟨Scan the template $\langle v_j \rangle$, putting the resulting token list in *hold_head* 958⟩ Used in section 953.
- ⟨Scan units and set cur_val to $x \cdot (cur_val + f/2^{16})$, where there are x sp per unit; **goto** *attach_sign* if the units are internal 479⟩ Used in section 474.

- ⟨Search *eqtb* for equivalents equal to *p* 273⟩ Used in section 190.
- ⟨Search *hyph_list* for pointers to *p* 1108⟩ Used in section 190.
- ⟨Search *save_stack* for equivalents that point to *p* 307⟩ Used in section 190.
- ⟨Select the appropriate case and **return** or **goto** *common_ending* 535⟩ Used in section 527.
- ⟨Set initial values of key variables 21, 23, 24, 74, 77, 80, 97, 118, 184, 233, 272, 276, 294, 309, 390, 409, 465, 507, 516, 547, 577, 582, 620, 623, 633, 677, 681, 688, 697, 709, 711, 724, 818, 828, 836, 859, 945, 1103, 1165, 1208, 1443, 1458, 1476, 1521, 1549, 1569, 1582, 1626, 1631, 1703, 1748, 1814, 1833, 1857⟩ Used in section 8.
- ⟨Set line length parameters in preparation for hanging indentation 1023⟩ Used in section 1022.
- ⟨Set the glue in all the unset boxes of the current list 979⟩ Used in section 974.
- ⟨Set the glue in node *r* and change it from an unset node 982⟩ Used in section 981.
- ⟨Set the unset box *q* and the unset boxes in it 981⟩ Used in section 979.
- ⟨Set the value of *b* to the badness for shrinking the line, and compute the corresponding *fit_class* 1027⟩
Used in section 1025.
- ⟨Set the value of *b* to the badness for stretching the line, and compute the corresponding *fit_class* 1026⟩
Used in section 1025.
- ⟨Set the value of *b* to the badness of the last line for shrinking, compute the corresponding *fit_class*, and **goto** *found* 1845⟩ Used in section 1843.
- ⟨Set the value of *b* to the badness of the last line for stretching, compute the corresponding *fit_class*, and **goto** *found* 1844⟩ Used in section 1843.
- ⟨Set the value of *output_penalty* 1188⟩ Used in section 1187.
- ⟨Set the value of *x* to the text direction before the display 1728⟩ Used in sections 1729 and 1731.
- ⟨Set up data structures with the cursor following position *j* 1083⟩ Used in section 1081.
- ⟨Set up the hlist for the display line 1742⟩ Used in section 1741.
- ⟨Set up the values of *cur_size* and *cur_mu*, based on *cur_style* 877⟩ Used in sections 894, 900, 901, 904, 928, 934, 936, and 937.
- ⟨Set variable *c* to the current escape character 261⟩ Used in section 63.
- ⟨Set variable *w* to indicate if this case should be reported 1772⟩ Used in sections 1771 and 1773.
- ⟨Ship box *p* out 668⟩ Used in section 666.
- ⟨Show equivalent *n*, in region 1 or 2 241⟩ Used in section 270.
- ⟨Show equivalent *n*, in region 3 247⟩ Used in section 270.
- ⟨Show equivalent *n*, in region 4 251⟩ Used in section 270.
- ⟨Show equivalent *n*, in region 5 260⟩ Used in section 270.
- ⟨Show equivalent *n*, in region 6 269⟩ Used in section 270.
- ⟨Show the auxiliary field, *a* 237⟩ Used in section 236.
- ⟨Show the box context 1678⟩ Used in section 1676.
- ⟨Show the box packaging info 1677⟩ Used in section 1676.
- ⟨Show the current contents of a box 1472⟩ Used in section 1469.
- ⟨Show the current meaning of a token, then **goto** *common_ending* 1470⟩ Used in section 1469.
- ⟨Show the current value of some parameter or register, then **goto** *common_ending* 1473⟩ Used in section 1469.
- ⟨Show the font identifier in *eqtb*[*n*] 252⟩ Used in section 251.
- ⟨Show the halfword code in *eqtb*[*n*] 253⟩ Used in section 251.
- ⟨Show the status of the current page 1161⟩ Used in section 236.
- ⟨Show the text of the macro being expanded 427⟩ Used in section 415.
- ⟨Simplify a trivial box 895⟩ Used in section 894.
- ⟨Skip to `\else` or `\fi`, then **goto** *common_ending* 526⟩ Used in section 524.
- ⟨Skip to node *ha*, or **goto** *done1* if no hyphenation should be attempted 1071⟩ Used in section 1069.
- ⟨Skip to node *hb*, putting letters into *hu* and *hc* 1072⟩ Used in section 1069.
- ⟨Sort *p* into the list starting at *rover* and advance *p* to *rlink*(*p*) 150⟩ Used in section 149.
- ⟨Sort the hyphenation op tables into proper order 1120⟩ Used in section 1127.
- ⟨Split off part of a vertical box, make *cur_box* point to it 1258⟩ Used in section 1255.
- ⟨Squeeze the equation as much as possible; if there is an equation number that should go on a separate line by itself, set *e* ← 0 1377⟩ Used in section 1375.

- ⟨Start a new current page 1166⟩ Used in sections 233 and 1192.
- ⟨Start stream of page/form contents 757⟩ Used in section 752.
- ⟨Store additional data for this feasible break 1847⟩ Used in section 1029.
- ⟨Store additional data in the new active node 1848⟩ Used in section 1019.
- ⟨Store *cur_box* in a box register 1253⟩ Used in section 1251.
- ⟨Store maximum values in the *hyf* table 1099⟩ Used in section 1098.
- ⟨Store *save_stack*[*save_ptr*] in *eqtb*[*p*], unless *eqtb*[*p*] holds a global value 305⟩ Used in section 304.
- ⟨Store all current *lc_code* values 1853⟩ Used in section 1852.
- ⟨Store hyphenation codes for current language 1852⟩ Used in section 1135.
- ⟨Store the current token, but **goto** *continue* if it is a blank space that would become an undelimited parameter 419⟩ Used in section 418.
- ⟨Store the packet being built 718⟩ Used in section 717.
- ⟨Subtract glue from *break_width* 1012⟩ Used in section 1011.
- ⟨Subtract the width of node *v* from *break_width* 1015⟩ Used in section 1014.
- ⟨Suppress expansion of the next token 393⟩ Used in section 391.
- ⟨Swap the subscript and superscript into box *x* 916⟩ Used in section 912.
- ⟨Switch to a larger accent if available and appropriate 914⟩ Used in section 912.
- ⟨Tell the user what has run away and try to recover 360⟩ Used in section 358.
- ⟨Terminate the current conditional and skip to **\fi** 536⟩ Used in section 391.
- ⟨Test box register status 531⟩ Used in section 527.
- ⟨Test if an integer is odd 530⟩ Used in section 527.
- ⟨Test if two characters match 532⟩ Used in section 527.
- ⟨Test if two macro texts match 534⟩ Used in section 533.
- ⟨Test if two tokens match 533⟩ Used in section 527.
- ⟨Test relation between integers or dimensions 529⟩ Used in section 527.
- ⟨The em width for *cur_font* 584⟩ Used in section 481.
- ⟨The x-height for *cur_font* 585⟩ Used in section 481.
- ⟨Tidy up the parameter just scanned, and tuck it away 426⟩ Used in section 418.
- ⟨Transfer node *p* to the adjustment list 829⟩ Used in section 823.
- ⟨Transplant the post-break list 1058⟩ Used in section 1056.
- ⟨Transplant the pre-break list 1059⟩ Used in section 1056.
- ⟨Treat *cur_chr* as an active character 1328⟩ Used in sections 1327 and 1331.
- ⟨Try the final line break at the end of the paragraph, and **goto** *done* if the desired breakpoints have been found 1047⟩ Used in section 1037.
- ⟨Try to allocate within node *p* and its physical successors, and **goto** *found* if allocation was possible 145⟩ Used in section 143.
- ⟨Try to break after a discretionary fragment, then **goto** *done5* 1043⟩ Used in section 1040.
- ⟨Try to get a different log file name 561⟩ Used in section 560.
- ⟨Try to hyphenate the following word 1069⟩ Used in section 1040.
- ⟨Try to recover from mismatched **\right** 1368⟩ Used in section 1367.
- ⟨Types in the outer block 18, 25, 38, 101, 109, 131, 168, 230, 291, 322, 574, 621, 694, 707, 722, 1095, 1100, 1624, 1629, 1675⟩ Used in section 4.
- ⟨Undump a couple more things and the closing check word 1505⟩ Used in section 1479.
- ⟨Undump constants for consistency check 1484⟩ Used in section 1479.
- ⟨Undump pdftex data 1503⟩ Used in section 1479.
- ⟨Undump regions 1 to 6 of *eqtb* 1493⟩ Used in section 1490.
- ⟨Undump the ε -TeX state 1652⟩ Used in section 1484.
- ⟨Undump the array info for internal font number *k* 1499⟩ Used in section 1497.
- ⟨Undump the dynamic memory 1488⟩ Used in section 1479.
- ⟨Undump the font information 1497⟩ Used in section 1479.
- ⟨Undump the hash table 1495⟩ Used in section 1490.
- ⟨Undump the hyphenation tables 1501⟩ Used in section 1479.

- ⟨ Undump the string pool 1486 ⟩ Used in section 1479.
- ⟨ Undump the table of equivalents 1490 ⟩ Used in section 1479.
- ⟨ Update the active widths, since the first active node has been deleted 1035 ⟩ Used in section 1034.
- ⟨ Update the current height and depth measurements with respect to a glue or kern node p 1151 ⟩ Used in section 1147.
- ⟨ Update the current marks for *fire_up* 1827 ⟩ Used in section 1189.
- ⟨ Update the current marks for *vsplit* 1824 ⟩ Used in section 1154.
- ⟨ Update the current page measurements with respect to the glue or kern specified by node p 1179 ⟩ Used in section 1172.
- ⟨ Update the value of *printed_node* for symbolic displays 1032 ⟩ Used in section 1003.
- ⟨ Update the values of *first_mark* and *bot_mark* 1191 ⟩ Used in section 1189.
- ⟨ Update the values of *last_glue*, *last_penalty*, and *last_kern* 1171 ⟩ Used in section 1169.
- ⟨ Update the values of *max_h* and *max_v*; but if the page is too large, **goto done** 669 ⟩ Used in sections 668 and 751.
- ⟨ Update width entry for spanned columns 972 ⟩ Used in section 970.
- ⟨ Use code c to distinguish between generalized fractions 1358 ⟩ Used in section 1357.
- ⟨ Use node p to update the current height and depth measurements; if this node is not a legal breakpoint, **goto not_found** or *update_heights*, otherwise set pi to the associated penalty at the break 1148 ⟩ Used in section 1147.
- ⟨ Use size fields to allocate font information 592 ⟩ Used in section 588.
- ⟨ Wipe out the whatsit node p and **goto done** 1602 ⟩ Used in section 220.
- ⟨ Wrap up the box specified by node r , splitting node p if called for; set *wait* \leftarrow *true* if node p holds a remainder after splitting 1196 ⟩ Used in section 1195.
- ⟨ Write out Form stream header 756 ⟩ Used in section 752.
- ⟨ Write out PDF annotations 781 ⟩ Used in section 780.
- ⟨ Write out PDF bead rectangle specifications 786 ⟩ Used in section 780.
- ⟨ Write out PDF link annotations 782 ⟩ Used in section 780.
- ⟨ Write out PDF mark destinations 784 ⟩ Used in section 780.
- ⟨ Write out page object 769 ⟩ Used in section 759.
- ⟨ Write out pending PDF marks 780 ⟩ Used in section 759.
- ⟨ Write out pending forms 775 ⟩ Used in section 761.
- ⟨ Write out pending images 779 ⟩ Used in section 761.
- ⟨ Write out pending raw objects 773 ⟩ Used in section 761.
- ⟨ Write out resource lists 761 ⟩ Used in section 759.
- ⟨ Write out resources dictionary 762 ⟩ Used in section 759.