

# Notes On Programming in T<sub>E</sub>X

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## Abstract

This document contains notes which are intended for those who are interested in T<sub>E</sub>X programming. It is valuable for beginners as a first start with a lot of examples, and it is also valuable for experienced T<sub>E</sub>Xnicians who are interested in details about T<sub>E</sub>X programming. However, it is neither a complete reference, nor a complete manual of T<sub>E</sub>X.

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## 1 Introduction

This document is intended to provide a direct start with T<sub>E</sub>X programming (not necessarily T<sub>E</sub>X typesetting). The addressed audience consists of people interested in package or library writing.

At the time of this writing, this document is far from complete. Nevertheless, it might be a good starting point for interested readers. Consult the literature given below for more details.

## 2 Programming in T<sub>E</sub>X

### 2.1 Variables in Registers

T<sub>E</sub>X provides several different variables and associated registers which can be manipulated freely.

**\count***<num>*

There are 256 Integer registers which provide 32 Bit Integer arithmetics. The registers can be used for example with **\count0**=42 or **\count7**=**\macro** where **\macro** expands to a number.

The value of a register can be typeset using **\the***<register>*.

The value is now ‘42’.

The value is now ‘-123456’.

```
\count0=42
The value is now '\the\count0'.
\def\macro{-123456}
\count0=\macro
The value is now '\the\count0'.
```

The ‘=’ sign is optional and can be omitted. One thing is common among the registers: an assignment of the form **\count0**=*<...>* expands everything which follows until the expansion doesn’t need more numbers – even more than one following macro.

The value is now ‘123456789’.

```
\def\firstmacro{123}
\def\secondmacro{456}
\def\thirdmacro{789}
\count0=\firstmacro\secondmacro\thirdmacro
The value is now '\the\count0'.
```

The precise rules can be found in [2], but it should be kept in mind that care needs to be taken here. More than once, my code failed to produce the expected result because T<sub>E</sub>X kept expanding macros and the registers got unexpected results. Here is the correct method:

1. The value is now ‘42’.
2. The following code will absorb the ‘3’ of ‘3.’:  
. The value is now ‘12343’.
4. Use **\relax** after an assignment to end scanning:
5. The value is now ‘1234’.

```
1. \count0=42 % a white space after the number aborts the reading process.
The value is now '\the\count0'.
2. The following code will absorb the ‘3’ of ‘3.’:
\def\macro{1234}
\count0=\macro % a white space after a macro will be absorbed by TeX, so this is wrong.
3. The value is now '\the\count0'.
4. Use \textbackslash relax after an assignment to end scanning:
\count0=\macro\relax
5. The value is now '\the\count0'.
```

The command **\relax** tells T<sub>E</sub>X to “relax”: it stops scanning for tokens, but **\relax** doesn’t expand to anything.

**\dimen***<num>*

There are also 255 registers for fixed point numbers which are used pretty much in the same way as the **\count** registers – but **\dimen** register assignments require a unit like ‘cm’ or ‘pt’.

String access with ‘**\the**’ works in exactly the same way as for **\count** registers.

The value is now 1.0pt.

The value is now 0.0001pt.

The value is now 1234.5678pt.

```

\dimen0=1pt
The value is now \the\dimen0.
\dimen0=0.0001pt
The value is now \the\dimen0.
\def\macro{1234.5678}
\dimen0=\macro pt
The value is now \the\dimen0.

```

The same rules with expansion of macros after assignments apply here as well.

The `\dimen` registers perform their arithmetics internally with 32 bit scaled integers, so called ‘scaled point’ with unit ‘sp’. It holds  $1\text{pt}=65536\text{sp}=2^{16}\text{sp}$ . One of the 32 bits is used as sign. The total number range in pt is  $[-(2^{30}-1)/2^{16}, (2^{30}-1)/2^{16}] = [-16383.9998, +16383.9998]^1$ .

`\toks`*<number>*

There are also 255 token registers which can be thought of as special string variables. Of course, every macro assignment `\def\macro{<content>}` is also some kind of string variable, but token registers are special: their contents won’t be expanded when used with `\the\toks<number>`. This can be used for fine grained expansion control, see Section 2.3 below.

### 2.1.1 Allocating Registers

### 2.1.2 Using More than 256 Registers

## 2.2 Arithmetics in TeX

`\advance`*<register>* by*<quantity>*

The value is now 52.

```

\count0=42
\advance\count0 by 10
The value is now \the\count0.

```

The value is now 11.0pt.

```

\dimen0=1pt
\advance\dimen0 by 10pt
The value is now \the\dimen0.

```

`\multiply`*<register>* by*<integer>*

The value is now -420.

```

\count0=42
\multiply\count0 by -10
The value is now \the\count0.

```

The value is now 10.0pt.

```

\dimen0=0.5pt
\multiply\dimen0 by 20
The value is now \the\dimen0.

```

`\divide`*<register>* by*<integer>*

This allows integer division by *<integer>* with truncation.

The value is now 2.

```

\count0=5
\divide\count0 by 2
The value is now \the\count0.

```

Scaling of `\dimen` registers:

The value is now 0.5pt.

---

<sup>1</sup>Please note that this does not cover the complete range of a 32 bit integer, I do not know why.

```
\dimen0=10pt
\divide\dimen0 by 20
The value is now \the\dimen0.
```

`\dimen` $\langle number \rangle = \langle fixed\ point\ number\ without\ unit \rangle \backslash dimen \langle number \rangle$

This allows fixed point multiplication in `\dimen` registers.

```
The value is now 30.0003pt.
```

```
\dimen1=50pt
\dimen0=0.6\dimen1
The value is now \the\dimen0.
```

## 2.3 Expansion Control

Expansion is what  $\text{\TeX}$  does all the time. Thus, expansion control is a key concept for understanding how to program in  $\text{\TeX}$ .

The first thing to know is:  $\text{\TeX}$  deals the input as a long, long sequence of “tokens”. A token is the smallest unit which is understood by  $\text{\TeX}$ . Each character becomes a token the first time it is seen by  $\text{\TeX}$ . Every macro becomes a (single!) token the first time it is seen by  $\text{\TeX}$ .

The second thing to know is what characters are *before*  $\text{\TeX}$  has seen them. Although this knowledge is rarely needed in every day’s life, it is nevertheless important. The characters which are in the input document are nothing but characters at first. Even the characters known to have a special meaning like ‘%’, ‘\’ or the braces ‘{ }’ are *not* special – until they have been converted to a token. This happens when  $\text{\TeX}$  encounters them the first time during its linear processing of the character stream. A token stays a token – and it will remain the same token forever. If you manage to tell  $\text{\TeX}$  that ‘\’ is a normal character and  $\text{\TeX}$  sees just one backslash, this backslash will be a normal character token – even if the meaning of all following backslashes is again special.

Now, we are given a very long list of tokens  $\langle token1 \rangle \langle token2 \rangle \langle token3 \rangle \langle token4 \rangle \langle token5 \rangle \dots$ .  $\text{\TeX}$  processes these tokens one-by-one in linear sequence. If  $\langle token1 \rangle$  is a character token like ‘a’, it is typeset. This is not what I want to write about here now; my main point is how to program in  $\text{\TeX}$ <sup>2</sup>. So, the interesting thing in these notes is when  $\langle token1 \rangle$  is a macro.

### 2.3.1 Macros

We have already seen some applications of macros above. Actually, most users who are willing to read notes about  $\text{\TeX}$  programming will have seen macros and may have written some on their own – for example using `\newcommand` (`\newcommand` is a “more high-level” version of `\def` used only in  $\text{\LaTeX}$ ).

A macro has a name and is treated as an elementary token in  $\text{\TeX}$  (even if the name is very long). A macro has replacement text. As soon as  $\text{\TeX}$  encounters a macro, it replaces its occurrence with the replacement text. Furthermore, a macro can consume one or more of the following tokens as arguments.

```
Executing it: ‘This here is actually the replacement text.’.
```

```
\def\macro{This here is actually the replacement text.}
Executing it: ‘\macro’.
```

```
Invoking it: replacement with first argument=hello!.
```

```
\def\macro#1{replacement with first argument=#1}
Invoking it: \macro{hello!}.
```

This here is not really a surprise. What might come as a surprise is that the accepted arguments can be pretty much anything.

```
Invoking it: replacement with arguments: ‘a’ and ‘sign’.
```

```
\def\macro#1-#2.{replacement with arguments: ‘#1’ and ‘#2’..}
Invoking it: \macro a-sign.
```

The last example `\macro` runs through the token list which follows the occurrence of `\macro`. This token list is “a-sign.”. Macro expansion is greedy, that means the first matching pattern is used. Now, our `\macro`

<sup>2</sup>Of course, typesetting is an art in itself and there is a lot to read about it. Just not here in these notes.

expected something, then a minus sign ‘-’, then another (possibly long) argument, then a period ‘.’. The argument between `\macro` and the minus sign is available as `#1` and the tokens between the minus sign and the period as `#2`.

I found arguments ‘42’, ‘43’ and ‘44’.

```
\def\macro(#1,#2,#3){I found arguments ‘#1’, ‘#2’ and ‘#3’}
\macro(42,43,44)
```

As we have seen, macros can be used to manipulate the input tokens by expansion: they take some input arguments (maybe none) away and insert other tokens into the input token list. These tokens will be the next to process. We will soon learn more about that.

There is a command which helps to understand what T<sub>E</sub>X does here:

`\meaning`*<macro>*

This command expands to the contents of *<macro>* as it is seen by T<sub>E</sub>X.

```
\def\macro{Replacement \textmacro text \count0=42 \the\count0}
\message{Debug message: ‘\meaning\macro’}
```

As result, the log file and terminal output will contain

Debug message: ‘macro:->Replacement \textmacro text \count 0=42 \the \count 0.’

The last example already shows something about `\def`: the replacement text can still contain other macros.

`\def`*<\macroname>**<argument pattern>*{*<replacement text>*}

A new macro named *<macroname>* will be defined (or re-defined). The *<replacement text>* is the macro body, whenever the macro is executed, it expands to *<replacement text>*. The *<replacement text>* is a token list which can contain other macros. On the time of the definition, T<sub>E</sub>X does *not* process (expand) the *<replacement text>*.

The *<replacement text>* will only be expanded if the macro is executed. This does also apply to any macros which are inside of *<replacement text>*.

Now, I execute it: Macro two contains This is macro one..

Now, I execute the second macro again: Macro two contains Redefined macroone..

```
\def\macroone{This is macro one}
\def\macrotwo{Macro two contains \macroone}
Now, I execute it: \macrotwo.
\def\macroone{Redefined macroone}
Now, I execute the second macro again: \macrotwo.
```

Macros can be defined almost everywhere in a T<sub>E</sub>X document. They can also be invoked almost everywhere.

The *<argument pattern>* is a token list which can contain simple strings or macro parameters ‘*#<number>*’ or other macro tokens. The *<number>* of the first parameter is always 1, the second must have 2 and so on up to at most 9. Valid argument patterns are ‘*#1#2#3*’, ‘*(#1,#2,#3)*’ or ‘*---\relax*’. If T<sub>E</sub>X executes a macro, it searches for *<argument pattern>* in the input token list until the first match is found. If no match can be found, it aborts with a (more or less helpful) error message.

Got ‘g’

```
\def\macroone abc{\macrotwo}
\def\macrotwo def{\macrothree}
\def\macrothree#1{Got ‘#1’}
\macroone abcdefg
```

The last example contains three macro definitions. Then, T<sub>E</sub>X encounters `\macroone`. The input token list is now

‘`\macroone abcdefg`’.

The space(s) following `\macroone` are ignored by T<sub>E</sub>X, they delimit the *<\macroname>*. Now, T<sub>E</sub>X attempts to find matches for *<argument pattern>*. It expects ‘`abc`’ – and it finds ‘`abc`’. These three

tokens are *removed* from the input token list, and T<sub>E</sub>X inserts the replacement text of `\macroone` which is `\macrotwo`. At that time, the input token list is

`'\macrotwo defg'`.

Now, the same game continues with `\macrotwo`: T<sub>E</sub>X searches for the expected  $\{\langle argument pattern \rangle\}$  which is `'def'`, erases these tokens from the input token list and inserts the replacement text of `\macrotwo` instead. This yields

`'\macrothree g'`.

Finally, `\macrothree` expects one parameter token (or a token list enclosed in parenthesis). The next token is `'g'`, which is consumed from the input token list and the replacement text is inserted – and `'#1'` is replaced by `'g'`. Then, the token list is

`'Got 'g''`.

This text is finally typeset (because it doesn't expand further).

What we have seen now is how T<sub>E</sub>X macros can be used to modify the token list. It should be noted explicitly that macro expansion does is in no way limited to those tokens provided inside of  $\{\langle replacement text \rangle\}$  – if the last argument in  $\{\langle replacement text \rangle\}$  is a macro which requires arguments, these arguments will be taken from the following tokens. Using nested macros, one can even process a complete part of the token list, in a manner of loops (but we don't know yet how to influence macro expansion conditionally, that comes later).

Let's try to solve the following task. Suppose you have a macro named `\point` with  $\langle argument pattern \rangle$  `'(#1,#2)'`, i.e.

```
\def\point(#1,#2){we do something with #1 and #2}.
```

Suppose furthermore that you want to invoke `\point` with the contents which is stored in another macro. After all, macros are some kind of string variables – it makes sense to accumulate or generate string variables which will then be used as input for other macros. Let's assume we have `\temp` and `\temp` contains `'(42,1234)'`. A first choice to invoke `\point` would be to use `\point\temp`. But: `\point` searches for an argument pattern which starts with `'('`, not with `\temp`! The invocation fails.

`\expandafter` $\langle token \rangle \langle next token \rangle$

The `\expandafter` command is an – at first sight confusing – method to alter the input token list. But: it solves our problem with `\point\temp`!

```
we do something with 42 and 1234
```

```
\def\point(#1,#2){we do something with #1 and #2}
\def\temp{(42,1234)}
\expandafter\point\temp
```

Why did that work!? The command `\expandafter` scans for the token after `\expandafter` in the input token list. This is `\point` in our case. Then, it scans for the next token which is `\temp` in our case (remember: macros are considered to be elementary tokens, just like characters `'a'` or so). The two scanned arguments are removed from the input token list. Then, `\expandafter` expands the  $\langle next token \rangle$  one time. In our case,  $\langle next token \rangle$  is `\temp`. The first level of expansion of `\temp` is `'(42,1234)'`. Then, `\expansion` inserts the (unexpanded)  $\langle token \rangle$  followed by the (expanded) contents of  $\langle next token \rangle$  back into the input token list. In single steps:

1. `\expandafter\point\temp`
2. Expand `\expandafter`: next two tokens are `'\point\temp'`.
3. Use `\point` as  $\langle token \rangle$  and `\temp` as  $\langle next token \rangle$ .
4. Expand `\temp` once, which leads to the tokens `'(42,1234)'`.
5. re-insert  $\langle token \rangle$  and the expansion of  $\langle next token \rangle$  back into the input token list. The list is then `'\point(42,1234)'`.
6. Expand `\point` as next token.

A further example: suppose we want to invoke `\theimportantmacro{\langle argument \rangle}`. However,  $\{\langle argument \rangle\}$  is contained in another macro! Furthermore, `\theimportantmacro` is defined to take exactly one parameter and our desired argument may have more than one token (which means we need to surround it with braces). This can be solved by the listing below.

I got the pre-assembled argument ‘xyz’ here.

```
\def\theimportantmacro#1{I got the pre-assembled argument ‘#1’ here.}
\def\temp{xyz}
\expandafter\theimportantmacro\expandafter{\temp}
```

Now, what happens here? Let’s apply the rules step by step again:

1. After the initial definitions, the token list is `\expandafter\theimportantmacro\expandafter{\temp}`.
2.  $\text{\TeX}$  expands `\expandafter`, using `\theimportantmacro` as  $\langle token \rangle$  and the second `\expandafter` as  $\langle next token \rangle$ .
3. According to the rules,  $\text{\TeX}$  expands  $\langle next token \rangle$  once. But:  $\langle next token \rangle$  is again a macro, namely `\expandafter`! Does that make a difference? No:
  - (a) The token list after the second `\expandafter` is ‘`{\temp}`’ (3 tokens).
  - (b) The  $\langle token \rangle$  is thus ‘`{`’ and  $\langle next token \rangle$  is ‘`\temp`’.
  - (c) The expansion of  $\langle next token \rangle$  is ‘xyz’.
  - (d) The second `\expandafter` re-inserts its  $\langle token \rangle$  and expanded  $\langle next token \rangle$ , which is ‘`{xyz}`’.

Note that the closing brace ‘`}`’ has not been touched at all,  $\text{\TeX}$  hasn’t even seen it so far.

We come back from the recursion. Remember:  $\langle token \rangle$  is `\theimportantmacro` and the top-level expansion of  $\langle next token \rangle$  is – as we have seen above – ‘`{xyz}`’.

4.  $\text{\TeX}$  re-inserts  $\langle token \rangle$  and the expansion of  $\langle next token \rangle$  to the input token list, which leads to ‘`\theimportantmacro{xyz}`’.

The closing brace ‘`}`’ has not been touched, it simply resides in the input token list.

5.  $\text{\TeX}$  expands `\theimportantmacro`.

The  $\langle next token \rangle$  is expanded exactly once. We have already seen that if  $\langle next token \rangle$  is a macro which does substitutions on its own, these substitutions will be performed recursively. But what means ‘once’ exactly? We will need to use `\meaning` to check that (or the `\tracingmacros` tools) because we need to see what  $\text{\TeX}$  does.

So far, nothing has been typeset. But now: 4[This is macro one –2–].

```
\def\macroone{This is macro one \macrotwo}
\def\macrotwo{--2--}
\def\macrothree#1{\def\macrofour{4[#1]}}
\expandafter\macrothree\expandafter{\macroone}%
So far, nothing has been typeset. But now: \macrofour.
\message{We have macrofour = \meaning\macrofour}%
```

The logfile (and terminal) will now contain

‘We have macrofour = macro:->4[This is macro one \macrotwo ]’.

What happened? We can proceed as in the last example. After the two `\expandafter` expansions,  $\text{\TeX}$  finds the input token list

‘`\macrothree{This is macro one \macrotwo}`’

which, after execution, defines `\macrofour` to be ‘`This is macro one \macrotwo`’. The top-level expansion of `\macroone` has not expanded the nested call to `\macrotwo`.

So, `\expandafter` is a normal macro which can be expanded – and it is even possible to expand an `\expandafter` by another `\expandafter`.

What we have seen so far is

1. the `\def` command which stores *unexpanded* arguments in a macro variable and
2. the `\expandafter` which allows control over top-level expansion of macros (it expands one time).

$\text{\TeX}$  provides two more features for expansion control: the `\edef` macro and token registers.

**\edef** $\langle\textit{macroname}\rangle\langle\textit{argument pattern}\rangle\{\langle\textit{replacement text}\rangle\}$

The **\edef** command is the same as **\def** insofar as it defines a new macro. However, it expands  $\{\langle\textit{replacement text}\rangle\}$  until only unexpandable tokens remain (**\edef** = expanded definition).

```
\def\{a{3}
\def\{b{2\{a}
\def\{c{1\{b}
\def\{d{value=\{c}
\message{Macro 'd' is defined to be '\meaning\{d'}
\edef\{d{value=\{c}
\message{Macro 'd' is e-defined to be '\meaning\{d'}
\expandafter\def\expandafter\{d\expandafter\{c}
\message{Macro 'd' is defined to be '\meaning\{d' using \expandafter}
```

This listing results in the log-file output

Macro 'd' is defined to be 'macro:->value=\{c '

Macro 'd' is e-defined to be 'macro:->value=123'

Macro 'd' is defined to be 'macro:->1\{b ' using \expandafter

So, **\def** does not expand at all, **\edef** expands until it can't expand any further and the **\expandafter** construction expands **\{c** one time and defines **\{d** to be the result of this expansion.

Although possible, it might not occur too often to specify  $\langle\textit{argument pattern}\rangle$  for an **\edef** because the expansion is immediate in contrast to **\def**. But it works in the same way: the positional arguments #1, #2, ..., #9 will be replaced with their arguments.

The expansion of  $\{\langle\textit{replacement text}\rangle\}$  happens in the same way as the expansion the main token list of T<sub>E</sub>X.

Now, what exactly does “expands until only unexpandable tokens remain” mean? Our example indicates that the three tokens 1, 2 and 3 are not expandable while the macros **\{c**, **\{b** and **\{a** could be expanded. There is one large class of T<sub>E</sub>X commands which can't be expanded: any assignment operation. The example

```
\edef\{d{\count0=42}
\message{Macro 'd' is defined to be '\meaning\{d'}
\def\{a{1234}
\edef\{d{\advance\count0 by\{a}
\message{Macro 'd' is defined to be '\meaning\{d'}
```

yields the log-messages

Macro 'd' is defined to be 'macro:->\count 0=42' and

Macro 'd' is defined to be 'macro:->\advance \count 0 by1234'.

So, assignment and arithmetics operations are *not* expandable, they remain as executable tokens in the newly defined macro. This does also hold for **\let** and other assignment operations.

Interestingly, conditional expressions using **\if** ... **\fi** are expandable, but we will come to that later.

There is also a method to convert a macro temporarily into an unexpandable token: the **\noexpand** macro.

**\noexpand** $\langle\textit{expandable token}\rangle$

The **\noexpand** command is only useful inside of the  $\{\langle\textit{replacement text}\rangle\}$  of an **\edef** command. As soon as **\edef** encounters the **\noexpand**, the **\noexpand** will be removed and the  $\langle\textit{expandable token}\rangle$  will be converted into an unexpandable token. Thus, the code

```
\edef\{d{Invoke \noexpand\{a another macro}
\message{Macro 'd' is defined to be '\meaning\{d'}
```

yields the terminal output

Macro 'd' is defined to be 'macro:->Invoke \{a another macro'

because **\noexpand\{a** yields the token '**\{a**' (unexpanded)<sup>3</sup>.

<sup>3</sup>The **\noexpand** key is actually used to implement the L<sup>A</sup>T<sub>E</sub>X command **\protect**: L<sup>A</sup>T<sub>E</sub>X's concept of moveable arguments is implemented with **\edef**.



### 2.3.2 Token Registers

Now, we turn to token registers. As we have already seen in Section 2.1, a token register stores a token list. A macro does also store a token list in its  $\{\langle replacement\ text\rangle\}$ , so where is the difference? There are two differences:

1. Token registers are faster.
2. The contents of token registers will *never* be expanded.

I can't give numbers for the first point – I have just read it in [2]. But the second point allows expansion control. While `\edef` allows “infinite” expansion, token registers allow only top-level expansion, just like `\expandafter`. But they can be used in a more flexible (and often more efficient) way than `\expandafter`. The following examples demonstrates the second point.

```
\toks0={A \token list \a \b \count0=42 will never be expanded}
\edef\d{\the\toks0 }% the space token is important!
\message{Macro 'd' is defined to be '\meaning\d'}
```

Executing this code fragment yields the log output

Macro 'd' is defined to be 'macro:->A \token list \a \b \count 0=42 will never be expanded'.

So, the contents of `\toks0` has been copied unexpanded into `\d`, although we have just `\edef`. Note that the space token after `\the\toks0` is indeed important!  $\TeX$  uses it to delimit the integer 0. Without the space token, it would have continued scanning, even beyond the boundaries of the replacement text of `\edef` (see Section 2.1 for details about this scanning).

The example is very simple, and we could have done the same with `\expandafter` as before. But let's try something more difficult: we want to assemble a new macro which consists of different pieces. Each piece is stored in a macro, and for whatever reason, we only want top-level expansion of the single pieces. And: the pieces won't be adjacent to each other. We can assemble the target macro using the following example listing.

```
\def\piecea{a{xyz}}
\def\pieceb{\count0=42 }
\def\piecec{string \b}
\toks0=\expandafter{\piecea}
\toks1=\expandafter{\pieceb}
\toks2=\expandafter{\piecec}
\edef\d{I have \the\toks0 and \the\toks1 and \the\toks2}
\message{Macro 'd' is defined to be '\meaning\d'}
```

The first three lines define our pieces. Each of the macros `\piecea`, `\pieceb` and `\piecec` contains tokens which should not be expanded during the definition of `\d`. The three following lines assign the top-level expansion of our pieces into token registers. Since `\toks0={\piecea}` would have stored '`\piecea`' into the token register, we need to use `\expandafter` here<sup>4</sup>. Then, we use `\the\toks<number>` to insert the contents of a token list somewhere – in our case, into the expanded replacement text of our macro `\d`. Thus, the complete example yields the log-output

Macro 'd' is defined to be 'macro:->I have \a {xyz}and \count 0=42 and string \b '.

It is possible to get exactly the same result using (a lot of) `\expandafters`. Don't try it.

### 2.3.3 Summary of macro definition commands

Besides `\def` and `\edef`, there are some more commands which allow to define macros (although the main functionality is covered by `\def` and `\edef`). Here are the remaining definition commands.

**`\def`** $\langle\macroname\rangle\langle argument\ pattern\rangle\{\langle replacement\ text\rangle\}$

Defines a new macro named `\macroname` without expanding  $\{\langle replacement\ text\rangle\}$ , see above.

**`\edef`** $\langle\macroname\rangle\langle argument\ pattern\rangle\{\langle replacement\ text\rangle\}$

Defines a new macro named `\macroname`, expanding  $\{\langle replacement\ text\rangle\}$  completely (see above).

<sup>4</sup>We could have eliminated the `\piece*` macros by writing everything into token registers directly. But I think this example is more realistic.

`\let⟨newmacro⟩=⟨token⟩`

Defines or redefines `\newmacro` to be an equivalent to `⟨token⟩`. For example, `\let\ a=\ b` will create a new copy of macro `\ b`. The copy is named `\ a`, and it will have exactly the same `{⟨replacement text⟩}` and `⟨argument pattern⟩` as `\ b`.

It is also possible that `⟨token⟩` is something different than a macro, for example a named register or a single character.

`\gdef⟨macroname⟩⟨argument pattern⟩{⟨replacement text⟩}`

A shortcut for `\global\def`. It defines `\macroname` globally, independent of the current scope.

You should avoid macros which exist in both, the global namespace and a local scope, with different meanings. Section 2.4 explains more about scoping.

`\xdef⟨macroname⟩⟨argument pattern⟩{⟨replacement text⟩}`

A shortcut for `\global\edef`. It defines `\macroname` globally, independent of the current scope.

You should avoid macros which exist in both, the global namespace and a local scope, with different meanings. Section 2.4 explains more about scoping.

`\csname⟨expandable tokens⟩\endcsname`

This command is not a macro definition, it is a definition of a macro’s *name*. The “cs” means “control sequence”. The `\csname`, `\endcsname` pair defines a control sequence name (a macro name) using `⟨expandable tokens⟩`. The control sequence character ‘\’ will be prepended automatically by `\csname`.<sup>5</sup>

This here is normal usage: ‘Content’.

This here uses csname: ‘Content’.

```
\def\macro{Content}
This here is normal usage: ‘\macro’.
This here uses csname: ‘\csname macro\endcsname’.
```

The example demonstrates that `\csname⟨expandable tokens⟩\endcsname` is actually the same as if you had written `\⟨expandable tokens⟩` directly – but the `\csname` construction allows much more tokens inside of macro names:

I use a strange macro. Here is it: ‘Content’.

```
\expandafter\def\csname a01macro with.strange.chars\endcsname{Content}
I use a strange macro. Here is it: ‘\csname a01macro with.strange.chars\endcsname’.
```

The example uses `\expandafter` to expand `\csname` one time. The top-level expansion of `\csname` is a single token, namely the control sequence name. Then, `\def` is used to define a macro with the prepared macro name.

When `\csname` is expanded, it parses all tokens up to the next `\endcsname`. Those tokens will be expanded until only unexpandable tokens remain (as in `\edef`). The resulting string will be used to define a macro name (with the control sequence character ‘\’ prepended). The fact that `⟨expandable tokens⟩` is expanded allows to use “indirect” macro names:

I have just defined “macroonetwothree  
with replacement text ‘Content’.

```
\def\macro{onetwothree}
\expandafter\def\csname macro\macro\endcsname{Content}
I have just defined \expandafter\string\csname macro\macro\endcsname
with replacement text ‘\csname macro\macro\endcsname’.
```

I suppose the example is self-explaining, up to the `\string` command which is described below.

Due to this flexibility, `\csname` is used to implement all (?) of the available key–value packages in T<sub>E</sub>X.

<sup>5</sup>In fact, the contents of `\escapechar` will be used here. If its value is -1, no character will be prepended. The same holds for any occurrence where a backslash would be inserted by T<sub>E</sub>X commands.

`\string\macro`

This command does not define a macro. Instead, it returns a macro’s name as a sequence of separate tokens, including the control sequence token ‘\’.

I have just defined “macro” using “def”.

```
\def\macro{Content}
I have just defined '\string\macro' using '\string\def'.
```

You can also use `\string` on other tokens – for example characters. That doesn’t hurt, the character will be returned as-is.

### 2.3.4 Debugging Tools – Understanding and Tracing What T<sub>E</sub>X Does

`\message{(tokens)}`

`\meaning\macro`

`\tracingmacros=2`

`\tracingcommands=2`

`\tracingrestores=1`

## 2.4 The Scope of a Variable

Each programming language knows the concept of a scope: they limit the effect of variables or routines. However, T<sub>E</sub>X’s scoping mechanisms have not been designed for programming – T<sub>E</sub>X is a typesetting language. Many programming languages like C, C++, java or a lot of scripting languages define the scope of a variable using the place where the variable has been defined. For example, the C fragment

```
int i = 42;

{
    ++i;
    int i = 5;
}
```

changes the value of the outer `i` to 43. The inner `i` is 5, but it will be deleted as soon as the closing brace is encountered. It may even be possible to access both, the value of the inner `i` variable and the value of the outer `i` variable, at the same time.

In T<sub>E</sub>X, braces are also used for scopes. But: while T<sub>E</sub>X will also destroy any variables (macros) defined inside of a scope at the end of that scope, it will *also* undo any change which has been applied inside of that scope.

The value of `\i` is now 42.

```
\def\i{42}
{
    \def\i{43}
    \def\b{2}
}
The value of \textbackslash i is now \i.
```

The listing above defines `\i`, enters a local scope (a T<sub>E</sub>X “group”) and changes `\i`. However, due to T<sub>E</sub>X’s scoping rules, the old program state will be restored *completely* after returning from the local group! Neither the change to `\i` nor the definition of `\b` will survive. The same holds for register changes or other assignments.

T<sub>E</sub>X groups can be created in one of three ways: using curly braces<sup>6</sup>, using `\begingroup` or using `\bgroup`. Curly braces are seldom used to delimit T<sub>E</sub>X groups because the other commands are more flexible. If one uses curly braces, they need to match up – it is forbidden to have unmatched curly braces.

`\begingroup`

Starts a new T<sub>E</sub>X group (a local scope). The scope will be active until it will be closed by `\endgroup`. The `\endgroup` command can occur later in the main token list.

---

<sup>6</sup>Or other tokens with the correct category code, compare [2].

### `\endgroup`

Ends a T<sub>E</sub>X group which has been opened with `\begingroup`.

### `\bgroup`

A special variant of `\begingroup` which can also be used to delimit arguments to `\hbox` or `\vbox` (i.e. it avoids the necessity to provide matched curly braces in this context).

The `\bgroup` macro is also useful to test whether the next following character is an opening brace (see `\futurelet`).

If one just needs to open a T<sub>E</sub>X group, one should prefer `\begingroup`.

### `\egroup`

Closes a preceding `\bgroup`.

T<sub>E</sub>X does not know how to write into macros of an outer scope – except for the topmost (global) scope. This restriction is quite heavy if one needs to write complex structures: local variables should be declared inside of local groups, but changes to the structure should be written to the outer group. There is no direct possibility to do such a thing (except global variables).

#### 2.4.1 Global Variables

T<sub>E</sub>X knows only “global” variables and “local” variables. A local variable will be deleted at the end of the group in which it has been declared. All values assigned locally will also be restored to their old value at the end of the group.

A global variable, on the other hand, maintains the same value throughout *every* scope. Usually, the topmost scope is the same as the one used for global variables: if you define anything in your T<sub>E</sub>X document, you add commands on global scope. It is also possible to explicitly make assignments or definitions in the global scope.

### `\global`*<definition or assignment>*

The definition which follows `\global` immediately will be done globally.

```
{
  \global\def\alpha{123}
  \global\advance\count0 by3
  \global\toks0={34}
}
```

### `\globaldefs=-1|0|1` (initially 0)

I cite from [2]: “If the `\globaldefs` parameter is positive at the time of an assignment, a prefix of `\global` is automatically implied; but if `\globaldefs` is negative at the time of the assignment, a prefix of `\global` is ignored. If `\globaldefs` is zero (which it usually is), the appearance of nonappearance of `\global` determines whether or not a global assignment is made.”

#### 2.4.2 Transporting Changes to an Outer Group

There are a couple of methods to “transport” changes to an outer scope. Some are copy operations, some require to redo the changes again after the end of the scope. All of them can be realized using expansion control.

Let’s start with macro definitions which should be carried over the end of the group. I see the following methods:

- Copy the macro into a global, temporary variable (or even token register) and get that value after the scope.

```
\def\initialvalue{0}
{
  % do something:
  \def\initialvalue{42}
  \global\let\myglobaltemporary=\initialvalue
}
\let\initialvalue=\myglobaltemporary
```

The idea is that `\myglobaltemporary` is only used temporarily; its value is always undefined and can be overwritten at any time. This allows to use a local variable `\initialvalue`.

Please note that you should not use variables both globally and locally. This confuses  $\text{\TeX}$  and results in a slow-down at runtime.

- “Smuggle” the result outside of the current group. I know this idea from the implementation of [4] written by Mark Wibrow and Till Tantau. The idea is to use several `\expandafter`s and a `\def` to redefine the macro directly after the end of the group:

```
\def\smuggle#1\endgroup{%
  \expandafter\endgroup\expandafter\def\expandafter#1\expandafter{#1}%
}

\begingroup
  \def\variable{12}
  \edef\variable{\variable34}
  \edef\variable{\variable56}
  \smuggle\variable
\endgroup
```

The technique relies on groups started with `\begingroup` and ended with `\endgroup` because unmatched braces are not possible with `\def`. The effect is that after all those `\expandafter`s,  $\text{\TeX}$  encounters the token list

```
\endgroup\def\variable{123456}
```

at the end of the group.

- Use the aftergroup stack.  $\text{\TeX}$  has a special token stack of limited size which can be used to re-insert tokens after the end of a group. However, this does only work efficiently if the number of tokens which need to be transported is small and constant (say, at most three). It works by prefixing every token with `\aftergroup`, compare [2] for details.

Sometimes one needs to copy other variables outside of a scope. The trick with a temporary global variable works always, of course. But it is also possible to define a macro which contains commands to apply any required changes and transport that macro out of the scope.

## 2.5 Branching

Here we discuss some of the available branching constructions of  $\text{\TeX}$ , with emphasis on conditions involving numbers and tokens.

**ifnum** $\langle count/integer\ number\rangle=\langle count/integer\ number\rangle\langle true-block\rangle\langle else\langle false-block\rangle\backslash fi$

`\ifnum` compare integer numbers or integer registers (`\count` registers) and contains two branches, one is executed in the true case, the other in the case of false:

This is shown if above results to false.

```
\ifnum1=2 % this space is important.
This is shown if above were true.
\else
This is shown if above results to false.
\fi
```

Note that the `\else` with its  $\langle false-block\rangle$  is optional.

**ifdim** $\langle dimen/fixed\ point\ number\rangle=\langle dimen/fixed\ point\ number\rangle\langle true-block\rangle\langle else\langle false-block\rangle\backslash fi$

Similar to `\ifnum`, `\ifdim` compares two fixed point numbers or `\dimen` registers. The numbers must have a unit.

This is shown if above results to false.

```
\ifdim1pt=2pt % this space is important.
This is shown if above were true.
\else
This is shown if above results to false.
\fi
```

`ifx⟨token1⟩⟨token2⟩⟨true-block⟩\else⟨false-block⟩\fi`

`\ifx` is a bit more complex: It compares two *tokens* up to their first-level expansion.

This is shown if the two tokens have equal expansion.

```
\def\empty{\empty}
\ifx\empty\empty %
This is shown if the two tokens have equal expansion.
\else
This is shown if the two tokens expand to something different.
\fi
```

Here, we have defined a token `\empty` to be a replacement for `\empty` and subsequently have compared whether these two tokens are equal in first-level expansion. Note that the definition is actually nonsense. If  $\text{\TeX}$  ever were to go through the whole expansion – i.e. we would put `\empty` somewhere else – it would do so indefinitely. However, with `\ifx` only first-level expansion is done and compared. Hence, the statement evaluates to true.

Have a look at the following example:

This is shown if the two tokens expand to something different.

```
\def\empty{\relax}
\ifx\empty\relax %
This is shown if the two tokens have equal expansion.
\else
This is shown if the two tokens expand to something different.
\fi
```

On first glance, this should evaluate to true: `\empty` is defined as a replacement for `\relax`. But it does not. Why?

`\empty` is expanded to `\relax`, however `\relax` expanded has a different meaning, namely stop scanning and not `\relax` anymore. Hence, they are different and the statement is false! If the expansion in `\ifx` were to be taken till maximum, both would be equal but not in the case of a comparison on first-level expansion only.

`if⟨token1⟩⟨token2⟩⟨true-block⟩\else⟨false-block⟩\fi`

The `\if` comparison is closely related to the `\ifx` conditional, with one major exception: it expands tokens until it finds the next two unexpandable tokens. If these two tokens are the same, it expands to the *⟨true-block⟩*, otherwise to the *⟨false-block⟩*.

The `\if` conditional should be handled with care as it might produce undesirable effects. Use it only if you know what you do.

A useful example is if you *know* that a macro contains at most one character, and you want to test for a particular one:

This is shown for all other choices.

```
\def\choice{a}
\if b\choice
  This is shown for the ‘b’ choice.
\else
  This is shown for all other choices.
\fi
```

`iftrue⟨true-block⟩\else⟨false-block⟩\fi`

A “conditional” which always invokes the *⟨true-block⟩*.

`iffalse⟨true-block⟩\else⟨false-block⟩\fi`

A “conditional” which always invokes the *⟨false-block⟩*.

### 2.5.1 Boolean Variables

`\newif⟨if-name⟩`

You can declare a new “boolean variable” `\ifsupermanmode` by means of `\newif\ifsupermanmode`.

Afterwards, you can use the `\supermanmodetrue` and `\supermanmodefalse` switches to assign the boolean and `\ifsupermanmode` to check it.

The `<if-name>` has to start with `\if` (to support scans for nested `\if... \fi` pairs, see below).

### 2.5.2 Special Cases for Conditionals

Whenever you work with `\if...` and friends, you should know the following features:

1. `\if... \else... \fi` is expandable (including each of the single macros `\if...`, `\else` and `\fi`), which means you can even use it inside of `\edef`:

We have now `temp=macro:->The choice is 'a'`.

```
\def\choice{a}
\edef\temp{The choice is \if a\choice 'a'\else not 'a'\fi}
We have now \texttt{\string temp=\meaning\temp}.
```

The next token is '2'.3

```
\def\shownexttoken#1{The next token is '\texttt{\string#1}'.}
\def\mymacro{%
  \ifnum1=1 %
    \expandafter\shownexttoken%
  \fi%
}%
\mymacro 23
```

This example is tricky. What would have happened without the `\expandafter`! Well, `\shownexttoken` would be invoked with `#1=\fi`. This would lead to an error because the `\fi` would be missing, and it would spoil the effect since we do not want the `\fi` to be seen – we expected `#1=2`. The `\expandafter` first expands `\fi` (which simply removes the `\fi` without further effect) such that `\shownexttoken` will see the 2 token in our example above. This would also have worked if there was an `\else` branch instead of `\fi`.

2. You should generally make sure that the matching `\else` or `\fi` tokens are “directly reachable”, i.e. without token expansion.

The background here is that T<sub>E</sub>X works on a token-based level: Whenever it encounters an `\if...` statement, it evaluates it and scans tokens to find the matching end part (either an `\else` or an `\fi` token). But it will not expand tokens during this scan, although it will count nested `\if... \fi` pairs! Thus, if you are careless, it might become confused and your conditional will go awry.

## 2.6 Loops

As you have seen, in T<sub>E</sub>X we have a very specific control over token expansion. This makes it possible to construct even loops via means of recursion. In essence, a loop consist of the following parts:

- counter or, more generally, list of items
- incrementor, or more generally, a next item picker
- threshold or, more generally, an end list marker
- a check of the threshold or end marker, respectively

Leafing through the sections above, we realize that all of this is actually in place: We do know about counters, we do know about branching. Only the specifics of how to create these loops is still to be made clear. We will show both cases, the counting loop and the loop over a list of items in the following in detail.

In general, for a loop done via a recursion we need two definitions: One for the loop start and another for the loop step.

### 2.6.1 Counting loops

For a counting loop, we need a counter `\count0`, an incrementor `\advance`, a threshold 3 and a check `\ifnum\count=10` if the threshold has been reached.

```
The current value is '0'
The current value is '1'
The current value is '2'
The current value is '3'
```

```
\long\def\countingloop#1 in #2:#3#4{%
  #1=#2 %
  \loopcounter{#1}{#3}{#4}%
}

\long\def\loopcounter#1#2#3{%
  #3%
  \ifnum#1=#2 %
  \else%
    \advance#1 by1 %
    \loopcounter{#1}{#2}{#3}%
  \fi%
}

\countingloop{\count0} in 0:{3}{%
  The current value is '\the\count0'\par
}
```

There are some subtleties to the above example:

- We put a lot of % in the example. Why? Note that whenever T<sub>E</sub>X scans for a number – e.g. as in the case of `#1=#2` – it will continue scanning token by token, that is digit by digit, till he is sure that the number has ended, even over white space, and even expanding macros in case they themselves might not represent numbers again. Hence, % tells T<sub>E</sub>X to stop scanning. It is generally good practice to place % to tell T<sub>E</sub>X to stop scanning for more digits. However, there are some exceptions to it as well: In case of `\advance#1 by1` one should keep a white space in between, as well as in the case of `\ifnum#1=#2`.
- We placed the threshold 3 in `\countingloop{\count0} in 0:{3}` in curly brackets. Why? T<sub>E</sub>X otherwise will recognize only the token 1 if a threshold of e.g. 10 is given and stumble over the now remnant ‘extra’ argument 0. That is because a single letter represents a token to T<sub>E</sub>X. Hence, two letters are two tokens and – ungrouped – become two arguments. Here, we have to group the threshold to make clear what we mean.
- One last thing becomes clear first when debugging is activated: As loops are done by recursion, i.e. by expansion followed by expansion till some threshold is reached, we will end with a lot of `\fi`s in the above case. If we place `\tracingmacros=2 \tracingcommands=2` before the `\countingloop` call and inspect the log file this will become apparent. This is bad because T<sub>E</sub>X will keep a stack frame open for each `\if... \fi` sequence. If we now have a loop over 10.000 items ...
- It is not good practice to use one of the system counters, here `\count0`, because one can never be sure that is not used for something else or changed somewhere else. E.g. when the page is full, T<sub>E</sub>X will interrupt the current sequence of tokens to deal with creating a new page and finishing the old one, in this course changing `\count0`. Hence, we should also create our own counter.

Hence, we modify the example as follows:

```
The current value is '0'
The current value is '1'
The current value is '2'
The current value is '3'
```



```

\long\def\countingloop#1 in #2:#3#4{%
  #1=#2 %
  \loopcounter{#1}{#3}{#4}%
}

\long\def\loopcounter#1#2#3{%
  #3%
  \ifnum#1=#2 %
    \let\next=\relax%
  \else
    \advance#1 by1 %
    \def\next{\loopcounter{#1}{#2}{#3}}%
  \fi
  \next
}
\newcount\ourcounter

\countingloop{\ourcounter} in 0:{3}{%
  The current value is ‘\the\ourcounter’\par
}

```

Principally, nothing has changed in terms of the output. However, notice that we have introduced the macro `\next` which either recurses into the next level – but after the `\fi` statement has been given – or ends the recursion by simply containing `\relax`. Also, we have declared a new counter called `\ourcounter` that is safe from harm.

Finally, let us briefly summarize what happens in detail:

1. `\countingloop...` is expanded to an assignment `#1=#2` and another macro `\loopcounter...`
2. The assignment is done: `\ourcounter` is set to the starting value 0.
3. The actual loop macro is expanded to the command block – printing the current value – and an if statement.
4. The current value is printed.
5. `\ourcounter` is compared to the threshold 3 and ...
  - False, i.e. the if statement is expanded to an `\advance` statement followed by defining `\next` to be another call of the same macro loop.
  - True, i.e. `\next` is set to be just `\relax`.
6. The statement is still false: `\advance` will increase `\ourcounter` by one, it is now 1. `\next` is set to the loop macro.
7. The loop macro is again expanded, go to step 3. `\ourcounter` is ... 2 ... `\ourcounter` is 3.
8. Now the statement is true: `\next` is expanded to `\relax` and nothing happens.

### 2.6.2 Loops over list of items

Looping over a list of items is very similar, only we will need `\ifx` in place of `\ifnum` and we need some end marker instead of the threshold value. However, how do we specify the list itself? Let’s make some comma-separated list, e.g. `{a,b,c,d}` and call the end marker `\listingloopENDMARKER`.

```

The current item is ‘a’
The current item is ‘
b’
The current item is ‘
c’
The current item is ‘
,
The current item is ‘
d’
The current item is ‘
e’

```

```

\def\listingloopENDMARKER{\par \listingloopENDMARKER}
\long\def\listingloop#1in#2#3{%
  \looppicker{#1}{#3}#2,\listingloopENDMARKER,%
}%
\long\def\looppicker#1#2#3,{%
  \def\tempitem{#3}%
  \ifx\tempitem\listingloopENDMARKER
    \let\next=\relax%
  \else
    \def#1{#3}%
    #2%
    \def\next{\looppicker{#1}{#2}}%
  \fi
  \next
}%
\listingloop\x in{a,b,c,,d,e}{%
  The current item is '\x'
}

```

Again, we make clear the subtleties contained therein:

- We have defined `\listingloopENDMARKER` to replace itself. This is possible because `\ifx` will only compare first-level expansion, see Section 2.5.
- We seem to miss a white space in `...#1in#2...`. However, tokens are always ending with an additional white space as `\xin` is not equal to `\x in`. Hence, none is needed here and more than one white space would probably get gobbled.
- The definition `\looppicker#1#2#3,...` has three arguments but the recursive call `\looppicker{#1}{#2}` only gives two arguments!? This is the actual magic making this type of list possible! `TEX` is actually scanning beyond the scope of the given token to obtain the third argument. In effect, we are biting off piece by piece, list item by list item off the given list. All because we have stated an additional `,` – comma being the item separator – in the definition of the `\looppicker` macro. The expansion of the loop macro will always pick up one more item from the list concatenated to its end until it has reached the `\ENDMARKER`. This is added to the list’s very end on the loop’s start, and there it stops.

## 2.7 More On T<sub>E</sub>X

This document is far from complete. I recommend reading about conditional expressions in [3] (German, online version) or [2] (bounded book). Hints about loops can be found in the manual of `PGFPLOTS`, [1] and the manual of `PGF`, [4]. Moreover, `PGFPLOTS` and `PGF` come with a whole lot of utility functions which are documented in the source `.code.tex` files.

## 3 Special Tricks

### 3.1 Handling # in Arguments

More than once, I encountered the following difficulty: I wanted to collect an argument which contains the hash sign, `#`. That’s not particularly difficult, but it can lead to a lot of strange error messages when the resulting argument shall be processed! Consider

```

\def\collectargument#1{%
  \def\collectedcontent{#1}%
  \ifx\collectedcontent\empty
    It is empty.
  \else
    It is not empty, executing it: #1.
  \fi
}%

\collectargument{}% works

\collectargument{something}% works

\collectargument{% does not work!
  \def\something#1{which depends on #1}
}%

```

The code in this example is relatively simple: the `\collectargument` macro expects one argument and checks if it is empty (using `\ifx`, which is a common and reliable check for emptiness). If it is not empty, it executes it. The `\collectargument` macro works in most circumstances. More precisely: it works as long as there is *no* hash sign in its argument! In our example, the third call fails with “Illegal parameter number in definition of `\collectedcontent`.” which occurs during the `\def\collectedcontent{#1}` line (and  $\text{\TeX}$  has reasons for this message due to the special meaning of the parameter expansion).

The cure: redefine the `\collectargument` macro using

```
\def\collectargument#1{%
  \toks0={#1}%
  \edef\collectedcontent{\the\toks0}%
  \ifx\collectedcontent\empty
    It is empty.
  \else
    It is not empty, executing it: #1.
  \fi
}%
```

(you may want to allocate a temporary token register for this task). What is the difference? Well, the `\toks0={#1}` assignment introduces no special meaning for the hash sign `#`, and `\the\toks0` neither. Note, however, that this requires `\edef\collectedcontent` instead of `\def\collectedcontent` since the `\the` statement needs to be expanded. Everything works as expected.

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