# low level TeX

## tokens

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# 1 Introduction

Most users don't need to know anything about tokens but it happens that when TEXies meet in person (users group meetings), or online (support platforms) there always seem to pop up folks who love token speak. When you try to explain something to a user it makes sense to talk in terms of characters but then those token speakers can jump in and start correcting you. In the past I have been puzzled by this because, when one can write a decent macro that does the job well, it really doesn't matter if one knows about tokens. Of course one should never make the assumption that token speakers really know TEX that well or can come up with better solutions than users but that is another matter.[1]

That said, because in documents about TEX the word 'token' does pop up I will try to give a little insight here. But for using TEX it's mostly irrelevant. The descriptions below for sure won't match the proper token speak criteria which is why at a presentation for the 2020 user meeting I used the title "Tokens as I see them."

# 2 What are tokens

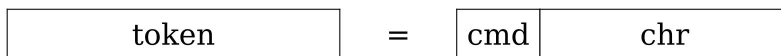
Both the words 'node' and 'token' are quite common in programming and also rather old which is proven by the fact that they also are used in the TEX source. A node is a storage container that is part of a linked list. When you input the characters `tex` the three characters become part of the current linked list. They become 'character' nodes (or in LuaTEX speak 'glyph' nodes) with properties like the font and the character referred to. But before that happens, the three characters in the input `t`, `e` and `x`, are interpreted as in this case being just that: characters. When you enter `\TeX` the input processors first sees a backslash and because that has a special meaning in TEX it will

[1] Talking about fashion: it would be more impressive to talk about TEX and friends as a software stack than calling it a distribution. Today, it's all about marketing.

read following characters and when done does a lookup in it's internal hash table to see what it actually is: a macro that assembled the word TeX in uppercase with special kerning and a shifted (therefore boxed) 'E'. When you enter $ TeX will look ahead for a second one in order to determine display math, push back the found token when there is no match and then enter inline math mode.

A token is internally just a 32 bit number that encodes what TeX has seen. It is the assembled token that travels through the system, get stored, interpreted and often discarded afterwards. So, the character 'e' in our example gets tagged as such and encoded in this number in a way that the intention can be derived later on.

Now, the way TeX looks at these tokens can differ. In some cases it will just look at this (32 bit) number, for instance when checking for a specific token, which is fast, but sometimes it needs to know some detail. The mentioned integer actually encodes a command (opcode) and a so called char code (operand). The second name is somewhat confusing because in many cases that code is not representing a character but that is not that relevant here. When you look at the source code of a TeX engine it is enough to know that a char can also be a sub command.




Back to the three characters: these become tokens where the command code indicates that it is a letter and the char code stores what letter we have at hand and in the case of LuaTeX and LuaMetaTeX these are Unicode values. Contrary to the traditional 8 bit TeX engine, in the Unicode engines an utf sequence is read, but these multiple bytes still become one number that will be encoded in the token number. In order to determine that something is a letter the engine has to be told (which is what a macro package does when it sets up the engine). For instance, digits are so called other characters and the backslash is called escape. Every TeX user knows that curly braces are special and so are dollar symbols and hashes. If this rings a bell, and you relate this to catcodes, you can indeed assume that the command codes of these tokens have the same numbers as the catcodes. Given that Unicode has plenty of characters slots you can imagine that combining 16 catcode commands with all the possible Unicode values makes a large repertoire of tokens.

There are more commands than the 16 basic characters related ones, in LuaMetaTeX we have just over 150 command codes (LuaTeX has a few more but they are also organized differently). Each of these codes can have a sub command, For instance the primitives `\vbox` and `\hbox` are both a `make_box_cmd` (we use the symbolic name here) and in LuaMetaTeX the first one has sub command code 9 (`vbox_code`) and the second one has code 10 (`hbox_code`). There are twelve primitives that are in the same category.

The many primitives that make up the core of the engine are grouped in a way that permits processing similar ones with one function and also makes it possible to distinguish between the way commands are handled, for instance with respect to expansion.

Now, before we move on it is important to know that al these codes are in fact abstract numbers. Although it is quite likely that engines that are derived from each other have similar numbers (just more) this is not the case for LuaMetaTEX. Because the internals have been opened up (even more than in LuaTEX) the command and char codes have been reorganized in a such a way that exposure is consistent. We could not use some of the reuse and remap tricks that the other engines use because it would simply be too confusing (and demand real in depth knowledge of the internals). This is also the reason why development took some time. You probably won't notice it from the current source but it was a very stepwise process. We not only had to make sure that all kept working (ConTEXt LMTX and LuaMetaTEX were pretty useable during the process), but also had to (re)consider intermediate choices.

So, input is converted into tokens, in most cases one-by-one. When a token is assembled, it either gets stored (deliberately or as part of some look ahead scanning), or it immediately gets (what is called:) expanded. Depending on what the command is, some action is triggered. For instance, a character gets appended to the node list immediately. An `\hbox` command will start assembling a box which its own node list that then gets some treatment: if this primitive was a follow up on `\setbox` it will get stored, otherwise it might end up in the current node list as so called hlist node. Commands that relate to registers have `0xFFFF` char codes because that is how many registers we have per category.

When a token gets stored for later processing it becomes part of a larger data structure, a so called memory word. These memory words are taken from a large pool of words and they store a token and additional properties. The info field contains the token value, the mentioned command and char. When there is no linked list, the link can actually be used to store a value, something that in LuaMetaTEX we actually do.

| 1 | info | link |
|---|---|---|
| 2 | info | link |
| 3 | info | link |
| n | info | link |

When for instance we say `\toks 0 {tex}` the scanner sees an escape, followed by 4 letters (`toks`) and the escape triggers a lookup of the primitive (or macro or ...) with that name, in this case a primitive assignment command. The found primitive (its property gets stored in the token) triggers scanning for a number and when that is successful

scanning of a brace delimited token list starts. The three characters become three letter tokens and these are a linked list of the mentioned memory words. This list then gets stored in token register zero. The input sequence `\the\toks 0` will push back a copy of this list into the input.

In addition to the token memory pool, there is also a table of equivalents. That one is part of a larger table of memory words where TEX stores all it needs to store. The 16 groups of character commands are virtual, storing these makes no sense, so the first real entries are all these registers (count, dimension, skip, box, etc). The rest is taken up by possible hash entries.

| | |
|---|---|
| main hash | null control sequence |
| | 128K hash entries |
| | frozen control sequences |
| | special sequences (undefined) |
| registers | 17 internal & 64K user glues |
| | 4 internal & 64K user mu glues |
| | 12 internal & 64K user tokens |
| | 2 internal & 64K user boxes |
| | 116 internal & 64K user integers |
| | 0 internal & 64K user attribute |
| | 22 internal & 64K user dimensions |
| specifications | 5 internal & 0 user |
| extra hash | additional entries (grows dynamic) |

So, a letter token `t` is just that, a token. A token referring to a register is again just a number, but its char code points to a slot in the equivalents table. A macro, which we haven't discussed yet, is actually just a token list. When a name lookup happens the hash table is consulted and that one runs in parallel to part of the table of equivalents. When there is a match, the corresponding entry in the equivalents table points to a token list.

| 1 | string index | equivalents or (next > n) index |
|---|---|---|
| 2 | string index | equivalents or (next > n) index |
| n | string index | equivalents or (next > n) index |
| n + 1 | string index | equivalents or (next > n) index |
| n + 2 | string index | equivalents or (next > n) index |
| n + m | string index | equivalents or (next > n) index |

It sounds complex and it actually also is somewhat complex. It is not made easier by the fact that we also track information related to grouping (saving and restoring), need reference counts for copies of macros and token lists, sometimes store information directly instead of via links to token lists, etc. And again one cannot compare LuaMetaTeX with the other engines. Because we did away with some of the limitations of the traditional engine we not only could save some memory but in the end also simplify matters (we're 32/64 bit after all). On the one hand some traditional speedups were removed but these have been compensated by improvements elsewhere, so overall processing is more efficient.

| 1 | level | type | flag | value |
|---|---|---|---|---|
| 2 | level | type | flag | value |
| 3 | level | type | flag | value |
| n | level | type | flag | value |

So, here LuaMetaTeX differs from other engines because it combines two tables, which is possible because we have at least 32 bits. There are at most `0xFFFF` levels but we need at most `0xFF` types. in LuaMetaTeX macros can have extra properties (flags) and these also need one byte. Contrary to the other engines, `\protected` macros are native and have their own command code, but `\tolerant` macros duplicate that (so we have four distinct macro commands). All other properties, like the `\permanent` ones are stored in the flags.

Because a macro starts with a reference count we have some room in the info field to store information about it having arguments or not. It is these details that make LuaMetaTeX a bit more efficient in terms of memory usage and performance than its ancestor LuaTeX. But as with the other changes, it was a very stepwise process in order to keep the system compatible and working.

## 3 Some implementation details

Sometimes there is a special head token at the start. This makes for easier appending of extra tokens. In traditional TeX node lists are forward linked, in LuaTeX they are

double linked[2]. Token lists are always forward linked. Shared token lists use the head node for a reference count.

For various reasons original TEX uses global variables temporary lists. This is for instance needed when we expand (nested) and need to report issues. But in LuaTEX we often just serialize lists and using local variables makes more sense. One of the first things done in LuaMetaTEX was to group all global variables in (still global) structures but well isolated. That also made it possible to actually get rid of some globals.

Because TEX had to run on machines that we nowadays consider rather limited, it had to be sparse and efficient. There are quite some optimizations to limit code and memory consumption. The engine also does its own memory management. Freed token memory words are collected in a cache and reused but they can get scattered which is not that bad, apart from maybe cache hits. In LuaMetaTEX we stay as close to original TEX as possible but there have been some improvements. The Lua interfaces force us to occasionally divert from the original, and that in fact might lead to some retrofit but the original documentation still mostly applies. However, keep in mind that in LuaTEX we store much more in nodes (each has a prev pointer and an attribute list pointer and for instance glyph nodes have some 20 extra fields compared to traditional TEX character nodes).

# 4 Other data management

There is plenty going on in TEX when it processes your input, just to mention a few:

- Grouping is handled by a nesting stack.
- Nested conditionals (`\if...`) have their own stack.
- The values before assignments are saved on the save stack.
- Also other local changes (housekeeping) ends up in the save stack.
- Token lists and macro aliases have references pointers (reuse).
- Attributes, being linked node lists, have their own management.

In all these subsystems tokens or references to tokens can play a role. Reading a single character from the input can trigger a lot of action. A curly brace tagged as begin group command will push the grouping level and from then on registers and some other quantities that are changed will be stored on the save stack so that after the group ends they can be restored. When primitives take keywords, and no match happens, tokens are pushed back into the input which introduces a new input level (also some stack).

[2] On the agenda of LuaMetaTEX is to use this property in the underlying code, that doesn't yet profit from this and therefore keep previous pointers in store.

When numbers are read a token that represents no digit is pushed back too and macro packages use numbers and dimensions a lot. It is a surprise that TEX is so fast.

# 5 Macros

There is a distinction between primitives, the build in commands, and macros, the commands defined by users. A primitive relates to a command code and char code but macros are, unless they are made an alias to something else, like a `\countdef` or `\let` does, basically pointers to a token list. There is some additional data stored that makes it possible to parse and grab arguments.

When we have a control sequence (macro) `\controlsequence` the name is looked up in the hash table. When found its value will point to the table of equivalents. As mentioned, that table keeps track of the cmd and points to a token list (the meaning). We saw that this table also stores the current level of grouping and flags.

If we say, in the input, `\hbox to 10pt {x\hss}`, the box is assembled as we go and when it is appended to the current node list there are no tokens left. When scanning this, the engine literally sees a backslash and the four letters `hbox`. However when we have this:

```
\def\MyMacro{\hbox to 10pt {x\hss}}
```

the `\hbox` has become one memory word which has a token representing the `\hbox` primitive plus a link to the next token. The space after a control sequence is gobbled so the next two tokens, again stored in a linked memory word, are letter tokens, followed by two other and two letter tokens for the dimensions. Then we have a space, a brace, a letter, a primitive and a brace. The about 20 characters in the input became a dozen memory words each two times four bytes, so in terms of memory usage we end up with quite a bit more. However, when TEX runs over that list it only has to interpret the token values because the scanning and conversion already happened. So, the space that a macro takes is more than compensated by efficient reprocessing.

# 6 Looking at tokens

When you say `\tracingall` you will see what the engine does: read input, expand primitives and macros, typesetting etc. You might need to set `\tracingonline` to get a bit more output on the console. One way to look at macros is to use the `\meaning` command, so if we have:

```
\permanent\protected\def\MyMacro#1#2{Do #1 or #2!}
```

we can say this:

```
\meaning    \MyMacro
\meaningless\MyMacro
\meaningfull\MyMacro
```

and get:

```
protected macro:#1#2->Do #1 or #2!
#1#2->Do #1 or #2!
permanent protected macro:#1#2->Do #1 or #2!
```

You get less when you ask for the meaning of a primitive, just its name. The `\meaningfull` primitive gives the most information. In LuaMetaTEX protected macros are first class commands: they have their own command code. In the other engines they are just regular macros with an initial token indicating that they are protected. There are specific command codes for `\outer` and `\long` macros but we dropped that in LuaMetaTEX. Instead we have `\tolerant` macros but that's another story. The flags that were mentioned can mark macros in a way that permits overload protection as well as some special treatment in otherwise tricky cases (like alignments). The overload related flags permits a rather granular way to prevent users from redefining macros and such. They are set via prefixes, and add to that repertoire: we have 14 prefixes but only some eight deal with flags (we can add more if really needed). The probably most wel known prefix is `\global` and that one will not become a flag: it has immediate effect.

For the above definition, the `\showluatokens` command will show a meaning on the console.

```
\showluatokens\MyMacro
```

This gives the next list, where the first column is the address of the token, the second one the command code, and the third one the char code. When there are arguments involved, the list of what needs to get matched is shown.

```
permanent protected control sequence: MyMacro
501263  19   49  match                  argument 1
501087  19   50  match                  argument 2
385528  20    0  end match
--------------
501090  11   68  letter                 D (U+00044)
 30833  11  111  letter                 o (U+0006F)
500776  10   32  spacer
385540  21    1  parameter reference
112057  10   32  spacer
```

```
431886  11  111  letter                o (U+0006F)
 30830  11  114  letter                r (U+00072)
 30805  10   32  spacer
500787  21    2  parameter reference
213412  12   33  other char            ! (U+00021)
```

In the next subsections I will give some examples. This time we use helper defined in a module:

```
\usemodule[system-tokens]
```

## 6.1 Example 1: in the input

```
\luatokentable{1 \bf{2} 3\what {!}}
```

| given token list: | | | | | | |
|---|---|---|---|---|---|---|
| 543282 | 12 | 49 | other char | 1 | U+00031 | |
| 32650 | 10 | 32 | spacer | | | |
| 538531 | 138 | 0 | protected call | | | bf |
| 32747 | 1 | 123 | left brace | | | |
| 543108 | 12 | 50 | other char | 2 | U+00032 | |
| 203842 | 2 | 125 | right brace | | | |
| 542992 | 10 | 32 | spacer | | | |
| 543165 | 12 | 51 | other char | 3 | U+00033 | |
| 158531 | 125 | 0 | undefined cs | | | what |
| 542910 | 1 | 123 | left brace | | | |
| 540378 | 12 | 33 | other char | ! | U+00021 | |
| 540484 | 2 | 125 | right brace | | | |

## 6.2 Example 2: in the input

```
\luatokentable{a \the\scratchcounter b \the\parindent \hbox to 10pt{x}}
```

| given token list: | | | | | | |
|---|---|---|---|---|---|---|
| 540332 | 11 | 97 | letter | a | U+00061 | |
| 543406 | 10 | 32 | spacer | | | |
| 542953 | 135 | 0 | the | | | the |
| 542736 | 108 | 123 | integer | | | scratchcounter |
| 543123 | 11 | 98 | letter | b | U+00062 | |
| 539153 | 10 | 32 | spacer | | | |
| 542853 | 135 | 0 | the | | | the |
| 540401 | 90 | 0 | internal dimen | | | parindent |
| 543045 | 30 | 14 | make box | | | hbox |
| 542965 | 11 | 116 | letter | t | U+00074 | |
| 543341 | 11 | 111 | letter | o | U+0006F | |
| 32716 | 10 | 32 | spacer | | | |

| | | | | | |
|---|---|---|---|---|---|
| 539282 | 12 | 49 | other char | 1 | U+00031 |
| 540389 | 12 | 48 | other char | 0 | U+00030 |
| 32727 | 11 | 112 | letter | p | U+00070 |
| 226978 | 11 | 116 | letter | t | U+00074 |
| 211396 | 1 | 123 | left brace | | |
| 543301 | 11 | 120 | letter | x | U+00078 |
| 542868 | 2 | 125 | right brace | | |

## 6.3 Example 3: user registers

```
\scratchtoks{foo \framed{\red 123}456}
```

```
\luatokentable\scratchtoks
```

| **token register: scratchtoks** | | | | | | |
|---|---|---|---|---|---|---|
| 560486 | 11 | 102 | letter | f | U+00066 | |
| 542767 | 11 | 111 | letter | o | U+0006F | |
| 543352 | 11 | 111 | letter | o | U+0006F | |
| 543224 | 10 | 32 | spacer | | | |
| 542766 | 141 | 0 | tolerant protected call | | | framed |
| 32667 | 1 | 123 | left brace | | | |
| 32668 | 138 | 0 | protected call | | | red |
| 543054 | 12 | 49 | other char | 1 | U+00031 | |
| 540445 | 12 | 50 | other char | 2 | U+00032 | |
| 211381 | 12 | 51 | other char | 3 | U+00033 | |
| 539352 | 2 | 125 | right brace | | | |
| 543376 | 12 | 52 | other char | 4 | U+00034 | |
| 543280 | 12 | 53 | other char | 5 | U+00035 | |
| 542745 | 12 | 54 | other char | 6 | U+00036 | |

## 6.4 Example 4: internal variables

```
\luatokentable\everypar
```

| **internal token variable: everypar** | | | | |
|---|---|---|---|---|
| 540495 | 138 | 0 | protected call | dotagsetparcounter |
| 540346 | 138 | 0 | protected call | page_otr_command_synchronize_side_floats |
| 542916 | 138 | 0 | protected call | checkindentation |
| 119138 | 137 | 0 | call | showparagraphnumber |
| 179407 | 138 | 0 | protected call | restoreinterlinepenalty |
| 543226 | 137 | 0 | call | flushnotes |
| 543231 | 138 | 0 | protected call | registerparoptions |
| 172030 | 137 | 0 | call | flushpostponednodedata |
| 211385 | 137 | 0 | call | typo_delimited_repeat |
| 226971 | 137 | 0 | call | spac_paragraphs_flush_intro |
| 540503 | 137 | 0 | call | typo_initial_handle |
| 542814 | 137 | 0 | call | typo_firstline_handle |

| | | | | |
|---|---|---|---|---|
| 211377 | 137 | 0 | call | spac_paragraph_wrap |
| 540417 | 138 | 0 | protected call | spac_paragraph_freeze |

## 6.5 Example 5: macro definitions

```
\protected\def\whatever#1[#2](#3)\relax
  {oeps #1 and #2 & #3 done ## error}

\luatokentable\whatever
```

| **protected control sequence: whatever** | | | | | | |
|---|---|---|---|---|---|---|
| 32749 | 19 | 49 | match | | argument 1 | |
| 211416 | 12 | 91 | other char | [ | U+0005B | |
| 542821 | 19 | 50 | match | | argument 2 | |
| 542781 | 12 | 93 | other char | ] | U+0005D | |
| 543216 | 12 | 40 | other char | ( | U+00028 | |
| 543190 | 19 | 51 | match | | argument 3 | |
| 543402 | 12 | 41 | other char | ) | U+00029 | |
| 542699 | 16 | 0 | relax | | | relax |
| 538403 | 20 | 0 | end match | | | |
| 542648 | 11 | 111 | letter | o | U+0006F | |
| 543106 | 11 | 101 | letter | e | U+00065 | |
| 539332 | 11 | 112 | letter | p | U+00070 | |
| 540379 | 11 | 115 | letter | s | U+00073 | |
| 543167 | 10 | 32 | spacer | | | |
| 539340 | 21 | 1 | parameter reference | | | |
| 543189 | 10 | 32 | spacer | | | |
| 32674 | 11 | 97 | letter | a | U+00061 | |
| 32714 | 11 | 110 | letter | n | U+0006E | |
| 32750 | 11 | 100 | letter | d | U+00064 | |
| 87878 | 10 | 32 | spacer | | | |
| 540473 | 21 | 2 | parameter reference | | | |
| 543117 | 10 | 32 | spacer | | | |
| 542966 | 12 | 38 | other char | & | U+00026 | |
| 543124 | 10 | 32 | spacer | | | |
| 542717 | 21 | 3 | parameter reference | | | |
| 542661 | 10 | 32 | spacer | | | |
| 540293 | 11 | 100 | letter | d | U+00064 | |
| 158532 | 11 | 111 | letter | o | U+0006F | |
| 543040 | 11 | 110 | letter | n | U+0006E | |
| 542982 | 11 | 101 | letter | e | U+00065 | |
| 543459 | 10 | 32 | spacer | | | |
| 543056 | 6 | 35 | parameter | | | |
| 543111 | 10 | 32 | spacer | | | |
| 32729 | 11 | 101 | letter | e | U+00065 | |
| 261633 | 11 | 114 | letter | r | U+00072 | |
| 542634 | 11 | 114 | letter | r | U+00072 | |
| 543178 | 11 | 111 | letter | o | U+0006F | |
| 539356 | 11 | 114 | letter | r | U+00072 | |

## 6.6 Example 6: commands

```
\luatokentable\startitemize
\luatokentable\stopitemize
```

| **frozen instance protected control sequence: startitemize** | | | | | | |
|---|---|---|---|---|---|---|
| 543121 | 141 | 0 | tolerant protected call | | | startitemgroup |
| 543295 | 12 | 91 | other char | [ | U+0005B | |
| 539174 | 11 | 105 | letter | i | U+00069 | |
| 540462 | 11 | 116 | letter | t | U+00074 | |
| 543105 | 11 | 101 | letter | e | U+00065 | |
| 32700 | 11 | 109 | letter | m | U+0006D | |
| 542619 | 11 | 105 | letter | i | U+00069 | |
| 540372 | 11 | 122 | letter | z | U+0007A | |
| 542825 | 11 | 101 | letter | e | U+00065 | |
| 543156 | 12 | 93 | other char | ] | U+0005D | |

| **frozen instance protected control sequence: stopitemize** | | | | |
|---|---|---|---|---|
| 543125 | 138 | 0 | protected call | stopitemgroup |

## 6.7 Example 7: commands

```
\luatokentable\doifelse
```

| **permanent protected control sequence: doifelse** | | | | | |
|---|---|---|---|---|---|
| 540525 | 19 | 49 | match | argument 1 | |
| 542700 | 19 | 50 | match | argument 2 | |
| 540274 | 20 | 0 | end match | | |
| 543183 | 132 | 26 | if test | | iftok |
| 542605 | 1 | 123 | left brace | | |
| 540377 | 21 | 1 | parameter reference | | |
| 540211 | 2 | 125 | right brace | | |
| 538562 | 1 | 123 | left brace | | |
| 543390 | 21 | 2 | parameter reference | | |
| 385132 | 2 | 125 | right brace | | |
| 32680 | 126 | 0 | expand after | | expandafter |
| 543407 | 137 | 0 | call | | firstoftwoarguments |
| 543148 | 132 | 3 | if test | | else |
| 32701 | 126 | 0 | expand after | | expandafter |
| 542822 | 137 | 0 | call | | secondoftwoarguments |
| 539266 | 132 | 2 | if test | | fi |

## 6.8 Example 8: nothing

```
\luatokentable\relax
```

| primitive control sequence: relax | | | | |
|---|---|---|---|---|
| 543458 | 16 | 0 | relax | relax |

## 6.9 Example 9: hashes

```
\edef\foo#1#2{(#1)(\letterhash)(#2)}  \luatokentable\foo
```

| control sequence: foo | | | | | |
|---|---|---|---|---|---|
| 540529 | 19 | 49 | match | | argument 1 |
| 539173 | 19 | 50 | match | | argument 2 |
| 32736 | 20 | 0 | end match | | |
| 543323 | 12 | 40 | other char | ( | U+00028 |
| 540545 | 21 | 1 | parameter reference | | |
| 540555 | 12 | 41 | other char | ) | U+00029 |
| 542762 | 12 | 40 | other char | ( | U+00028 |
| 543289 | 12 | 35 | other char | # | U+00023 |
| 543322 | 12 | 41 | other char | ) | U+00029 |
| 542564 | 12 | 40 | other char | ( | U+00028 |
| 542956 | 21 | 2 | parameter reference | | |
| 543096 | 12 | 41 | other char | ) | U+00029 |

## 6.10 Example 10: nesting

```
\def\foo#1{\def\foo##1{(#1)(##1)}}  \luatokentable\foo
```

| control sequence: foo | | | | | | |
|---|---|---|---|---|---|---|
| 540563 | 19 | 49 | match | | argument 1 | |
| 539374 | 20 | 0 | end match | | | |
| 542769 | 121 | 1 | def | | | def |
| 539298 | 137 | 0 | call | | | foo |
| 540195 | 6 | 35 | parameter | | | |
| 539296 | 12 | 49 | other char | 1 | U+00031 | |
| 539337 | 1 | 123 | left brace | | | |
| 543452 | 12 | 40 | other char | ( | U+00028 | |
| 540276 | 21 | 1 | parameter reference | | | |
| 543011 | 12 | 41 | other char | ) | U+00029 | |
| 539421 | 12 | 40 | other char | ( | U+00028 | |
| 538526 | 6 | 35 | parameter | | | |
| 32720 | 12 | 49 | other char | 1 | U+00031 | |
| 539215 | 12 | 41 | other char | ) | U+00029 | |
| 544591 | 2 | 125 | right brace | | | |

## 6.11 Remark

In all these examples the numbers are to be seen as abstractions. Some command codes and sub command codes might change as the engine evolves. This is why the LuaMetaTeX engine has lots of Lua functions that provide information about what number represents what command.

# 6.11 Colofon

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| --- | --- |
| ConTEXt | 2023.04.27 17:04 |
| LuaMetaTEX | 2.1008 |
| Support | www.pragma-ade.com |
| | contextgarden.net |