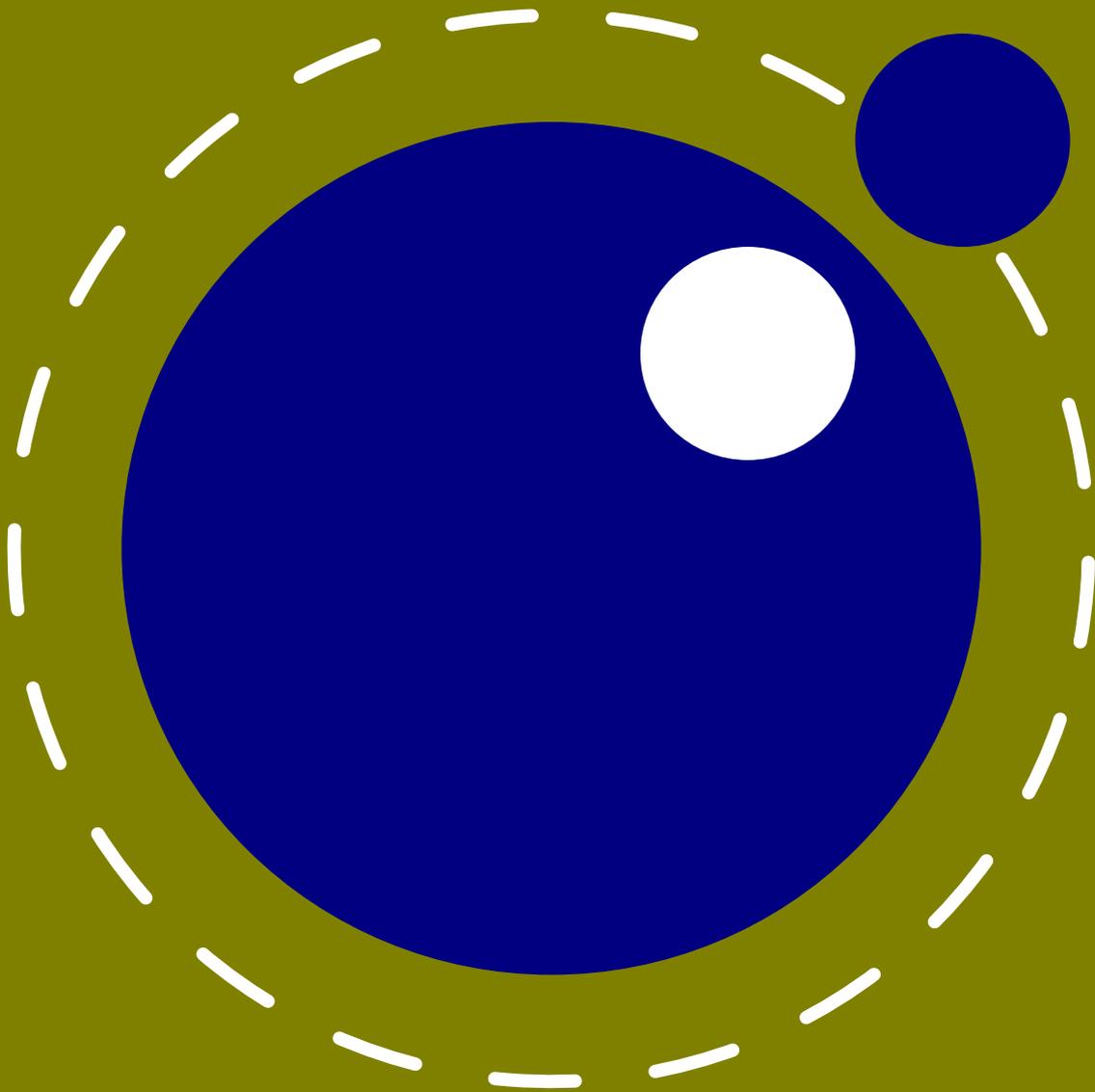


LuaMetaTeX

Reference

Manual



June 2021
Version 2.09.14

LuaMetaT_EX

Reference

Manual

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Introduction

Around 2005 we started the Lua \TeX project and it took about a decade to reach a state where we could consider the experiments to have reached a stable state. Pretty soon Lua \TeX could be used in production, even if some of the interfaces evolved, but Con \TeX t was kept in sync so that was not really a problem. In 2018 the functionality was more or less frozen. Of course we might add some features in due time but nothing fundamental will change as we consider version 1.10 to be reasonable feature complete. Among the reasons is that this engine is now used outside Con \TeX t too which means that we cannot simply change much without affecting other macro packages.

In reaching that state some decisions were delayed because they didn't go well with a current stable version. This is why at the 2018 Con \TeX t meeting those present agreed that we could move on with a follow up tagged Meta \TeX , a name we already had in mind for a while, but as Lua is an important component, it got expanded to LuaMeta \TeX . This follow up is a lightweight companion to Lua \TeX that will be maintained alongside. More about the reasons for this follow up as well as the philosophy behind it can be found in the document(s) describing the development. During Lua \TeX development I kept track of what happened in a series of documents, parts of which were published as articles in user group journals, but all are in the Con \TeX t distribution. I did the same with the development of LuaMeta \TeX .

The LuaMeta \TeX engine is, as said, a follow up on Lua \TeX . Just as we have Con \TeX t MkII for pdf \TeX and X \TeX , we have MkIV for Lua \TeX . For LuaMeta \TeX we have yet another version of Con \TeX t: LMTX. By freezing MkII, and at some point freezing MkIV, we can move on as we like, but we try to remain downward compatible where possible, something that the user interface makes possible. Although LuaMeta \TeX can be used for production we can also use it for possibly drastic experiments but without affecting Lua \TeX . Because we can easily adapt Con \TeX t to support both, no other macro package will be harmed when (for instance) the interface that the engine provides change as part of an experiment or cleanup of code. Of course, when we consider something to be useful, it can be ported back to Lua \TeX , but only when there are good reasons for doing so and when no compatibility issues are involved.

By now the code of these two related engines differs a lot so in retrospect it makes less sense to waste time on porting back. When considering this follow up one consideration was that a lean and mean version with an extension mechanism is a bit closer to original \TeX . Of course, because we also have new primitives, this is not entirely true. The basic algorithms remain the same but code got reshuffled and because we expose internal names of variables and such that is reflected in the code base (like more granularity in nodes and token commands). Delegating tasks to Lua already meant that some aspects, especially system dependent ones, no longer made sense and therefore had consequences for the interface at the system level. In LuaMeta \TeX more got delegated, like all file related operations. The penalty of moving even more responsibility to Lua has been compensated by (hopefully) harmless optimization of code in the engine and some more core functionality. In the process system dependencies have been minimalized.

This manual started as an adaptation of the Lua \TeX manual and therefore looks similar. Some chapters are removed, others were added and the rest has been (and will be further) adapted. It also discusses the (main) differences. Some of the new primitives or functions that show up in LuaMeta \TeX might show up in Lua \TeX at some point, but most will be exclusive to LuaMeta \TeX ,



so don't take this manual as reference for Lua_{TeX}! As long as we're experimenting we can change things at will but as we keep Con_{TeX}t LMTX synchronized users normally won't notice this. Often you can find examples of usage in Con_{TeX}t related documents and the source code so that serves a reference too.

For Con_{TeX}t users the LuaMeta_{TeX} engine will become the default. As mentioned, the Con_{TeX}t variant for this engine is tagged LMTX. The pair can be used in production, just as with Lua_{TeX} and MkIV. In fact, most users will probably not really notice the difference. In some cases there will be a drop in performance, due to more work being delegated to Lua, but on the average performance is much better, due to some changes below the hood of the engine. Memory consumption is also less. The timeline of development is roughly: from 2018 upto 2020 engine development, 2019 upto 2021 the stepwise code split between MkIV and LMTX, while in 2021 and 2022 we will (mostly) freeze MkIV and LMTX will be the default.

As this follow up is closely related to Con_{TeX}t development, and because we expect stock Lua_{TeX} to be used outside the Con_{TeX}t proper, there will be no special mailing list nor coverage (or pollution) on the Lua_{TeX} related mailing lists. We have the Con_{TeX}t mailing lists for that. In due time the source code will be part of the regular Con_{TeX}t distribution so that is then also the reference implementation: if needed users can compile the binary themselves.

This manual sometimes refers to Lua_{TeX}, especially when we talk of features common to both engine, as well as to LuaMeta_{TeX}, when it is more specific to the follow up. A substantial amount of time went into the transition and more will go in, so if you want to complain about LuaMeta_{TeX}, don't bother me. Of course, if you really need professional support with these engines (or _{TeX} in general), you can always consider contacting the developers.

Hans Hagen

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Lua_{TeX} Team : Hans Hagen, Hartmut Henkel, Taco Hoekwater, Luigi Scarso

remark: LuaMeta_{TeX} development is mostly done by Hans Hagen and in adapting the macros to the new features Wolfgang Schuster, who knows the code inside-out is a instrumental. In the initial phase Alan Braslau, who love playing with the three languages did extensive testing and compiled for several platforms. Later Mojca Miklavc make sure all compiles well on the buildbot infrastructure. After the first release more users got involved in testing. Many thanks for their patience! The development also triggered upgrading of the wiki support infrastructure where Taco Hoekwater and Paul Mazaitis have teamed up. So, progress all around.

remark: When there are non-intrusive features that also make sense in Lua_{TeX}, these will be applied in the experimental branch first, so that there is no interference with the stable release. However, given that in the meantime the code bases differs a lot, it is unlikely that much will trickle back. This is no real problem as there's not much demand for that anyway.

remark: Most Con_{TeX}t users seem always willing to keep up with the latest versions which means that LMTX is tested well. We can therefore safely claim that end of 2019 the code has become quite stable, although after that in some areas there were substantial additions. There



are no complaints about performance (on my 2013 laptop this manual compiles at 24.5 pps with LMTX versus 20.7 pps for the Lua_TE_X manual with MkIV). After updating some of the Con_TE_Xt code to use recently added features by the end of 2020 I could do more than 25.5 pps but don't expect spectacular bumps in performance (I need a new machine for that to happen). Probably no one notices it, but memory consumption stepwise got reduced too. And . . . the binary is still below 3 MegaBytes on all platforms.





1 The internals

This is a reference manual and not a tutorial. This means that we discuss changes relative to traditional \TeX and also present new (or extended) functionality. As a consequence we will refer to concepts that we assume to be known or that might be explained later. Because the $\text{Lua}\TeX$ and $\text{LuaMeta}\TeX$ engines open up \TeX there's suddenly quite some more to explain, especially about the way a (to be) typeset stream moves through the machinery. However, discussing all that in detail makes not much sense, because deep knowledge is only relevant for those who write code not possible with regular \TeX and who are already familiar with these internals (or willing to spend time on figuring it out).

So, the average user doesn't need to know much about what is in this manual. For instance fonts and languages are normally dealt with in the macro package that you use. Messing around with node lists is also often not really needed at the user level. If you do mess around, you'd better know what you're dealing with. Reading “The \TeX Book” by Donald Knuth is a good investment of time then also because it's good to know where it all started. A more summarizing overview is given by “ \TeX by Topic” by Victor Eijkhout. You might want to peek in “The ε - \TeX manual” too.

But ... if you're here because of Lua, then all you need to know is that you can call it from within a run. If you want to learn the language, just read the well written Lua book. The macro package that you use probably will provide a few wrapper mechanisms but the basic `\directlua` command that does the job is:

```
\directlua{tex.print("Hi there")}
```

You can put code between curly braces but if it's a lot you can also put it in a file and load that file with the usual Lua commands. If you don't know what this means, you definitely need to have a look at the Lua book first.

If you still decide to read on, then it's good to know what nodes are, so we do a quick introduction here. If you input this text:

```
Hi There ...
```

eventually we will get a linked lists of nodes, which in ascii art looks like:

```
H <=> i <=> [glue] <=> T <=> h <=> e <=> r <=> e ...
```

When we have a paragraph, we actually get something like this, where a `par` node stores some metadata and is followed by a `hlist` flagged as `indent box`:

```
[par] <=> [hlist] <=> H <=> i <=> [glue] <=> T <=> h <=> e <=> r <=> e ...
```

Each character becomes a so called glyph node, a record with properties like the current font, the character code and the current language. Spaces become glue nodes. There are many node types and nodes can have many properties but that will be discussed later. Each node points back to a previous node or next node, given that these exist. Sometimes multiple characters are represented by one glyph (shape), so one can also get:



```
[par] <=> [hlist] <=> H <=> i <=> [glue] <=> Th <=> e <=> r <=> e ...
```

And maybe some characters get positioned relative to each other, so we might see:

```
[par] <=> [hlist] <=> H <=> [kern] <=> i <=> [glue] <=> Th <=> e <=> r <=> e ...
```

Actually, the above representation is one view, because in LuaMetaTeX we can choose for this:

```
[par] <=> [glue] <=> H <=> [kern] <=> i <=> [glue] <=> Th <=> e <=> r <=> e ...
```

where glue (currently fixed) is used instead of an empty hlist (think of a `\hbox`). Options like this are available because want a certain view on these lists from the Lua end and the result being predicable is part of that.

It's also good to know beforehand that TeX is basically centered around creating paragraphs and pages. The par builder takes a list and breaks it into lines. At some point horizontal blobs are wrapped into vertical ones. Lines are so called boxes and can be separated by glue, penalties and more. The page builder accumulates lines and when feasible triggers an output routine that will take the list so far. Constructing the actual page is not part of TeX but done using primitives that permit manipulation of boxes. The result is handled back to TeX and flushed to a (often pdf) file.

```
\setbox\scratchbox\vbox\bgroup
  line 1\par line 2
\egroup
```

```
\showbox\scratchbox
```

The above code produces the next log lines that reveal how the engines sees a paragraph (wrapped in a `\vbox`):

```
1:4: > \box257=
1:4: \vbox[normal][16=1,17=1,47=1], width 483.69687, height 27.58083, depth 0.1416, direction l2r
1:4: \list
1:4: ..\hbox[line][16=1,17=1,47=1], width 483.69687, height 7.59766, depth 0.1416, glue 455.40097fil, direction l2r
1:4: ...list
1:4: ....\glue[left hang][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[left][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[parfillleft][16=1,17=1,47=1] 0.0pt
1:4: ....\par[newgraf][16=1,17=1,47=1], hangafter 1, hsize 483.69687, pretolerance 100, tolerance 3000, adjdemerits 10000, linepenalty 10, doublehyphendemerits 10000, finalhyphendemerits 5000, clubpenalty 2000, widowpenalty 2000, brokenpenalty 100, emergencystretch 12.0, parfillskip 0.0pt plus 1.0fil, hyphenationmode 499519
1:4: ....\glue[indent][16=1,17=1,47=1] 0.0pt
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+00006C l
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000069 i
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+00006E n
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000065 e
1:4: ....\glue[space][16=1,17=1,47=1] 3.17871pt plus 1.58936pt minus 1.05957pt, font 30
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000031 1
```



```

1:4: ....\penalty[line][16=1,17=1,47=1] 10000
1:4: ....\glue[parfill][16=1,17=1,47=1] 0.0pt plus 1.0fil
1:4: ....\glue[right][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[right hang][16=1,17=1,47=1] 0.0pt
1:4: ..\glue[par][16=1,17=1,47=1] 5.44995pt plus 1.81665pt minus 1.81665pt
1:4: ..\glue[baseline][16=1,17=1,47=1] 6.79396pt
1:4: ..\hbox[line][16=1,17=1,47=1], width 483.69687, height 7.59766, depth 0.1416, glue 455.40097fil, direction l2r
1:4: ...list
1:4: ....\glue[left hang][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[left][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[parfillleft][16=1,17=1,47=1] 0.0pt
1:4: ....\par[newgraf][16=1,17=1,47=1], hangafter 1, hsize 483.69687, pretolerance 100, tolerance 3000, adjdemerits 10000, linepenalty 10, doublehyphendemerits 10000, finalhyphendemerits 5000, clubpenalty 2000, widowpenalty 2000, brokenpenalty 100, emergencystretch 12.0, parfillskip 0.0pt plus 1.0fil, hyphenationmode 499519
1:4: ....\glue[indent][16=1,17=1,47=1] 0.0pt
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+00006C l
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000069 i
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+00006E n
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000065 e
1:4: ....\glue[space][16=1,17=1,47=1] 3.17871pt plus 1.58936pt minus 1.05957pt, font 30
1:4: ....\glyph[32768][16=1,17=1,47=1], language (n=1,l=2,r=3), hyphenationmode 499519, options 128 , font <30: DejaVuSerif @ 10.0pt>, glyph U+000032 2
1:4: ....\penalty[line][16=1,17=1,47=1] 10000
1:4: ....\glue[parfill][16=1,17=1,47=1] 0.0pt plus 1.0fil
1:4: ....\glue[right][16=1,17=1,47=1] 0.0pt
1:4: ....\glue[right hang][16=1,17=1,47=1] 0.0pt

```

The Lua \TeX engine provides hooks for Lua code at nearly every reasonable point in the process: collecting content, hyphenating, applying font features, breaking into lines, etc. This means that you can overload \TeX 's natural behaviour, which still is the benchmark. When we refer to 'callbacks' we means these hooks. The \TeX engine itself is pretty well optimized but when you kick in much Lua code, you will notices that performance drops. Don't blame and bother the authors with performance issues. In Con \TeX t over 50% of the time can be spent in Lua, but so far we didn't get many complaints about efficiency. Adding more callbacks makes no sense, also because at some point the performance hit gets too large. There are plenty of ways to achieve goals. For that reason: take remarks about Lua \TeX , features, potential, performance etc. with a natural grain of salt.

Where plain \TeX is basically a basic framework for writing a specific style, macro packages like Con \TeX t and L^A \TeX provide the user a whole lot of additional tools to make documents look good. They hide the dirty details of font management, language support, turning structure into typeset results, wrapping pages, including images, and so on. You should be aware of the fact that when you hook in your own code to manipulate lists, this can interfere with the macro package that you use. Each successive step expects a certain result and if you mess around to much, the engine eventually might bark and quit. It can even crash, because testing everywhere for what users can do wrong is no real option.

When you read about nodes in the following chapters it's good to keep in mind what commands relate to them. Here are a few:



COMMAND	NODE	EXPLANATION
<code>\hbox</code>	hlist	horizontal box
<code>\vbox</code>	vlist	vertical box with the baseline at the bottom
<code>\vtop</code>	vlist	vertical box with the baseline at the top
<code>\hskip</code>	glue	horizontal skip with optional stretch and shrink
<code>\vskip</code>	glue	vertical skip with optional stretch and shrink
<code>\kern</code>	kern	horizontal or vertical fixed skip
<code>\discretionary</code>	disc	hyphenation point (pre, post, replace)
<code>\char</code>	glyph	a character
<code>\hrule</code>	rule	a horizontal rule
<code>\vrule</code>	rule	a vertical rule
<code>\textdirection</code>	dir	a change in text direction

Whatever we feed into $\text{T}_{\text{E}}\text{X}$ at some point becomes a token which is either interpreted directly or stored in a linked list. A token is just a number that encodes a specific command (operator) and some value (operand) that further specifies what that command is supposed to do. In addition to an interface to nodes, there is an interface to tokens, as later chapters will demonstrate.

Text (interspersed with macros) comes from an input medium. This can be a file, token list, macro body or arguments, some internal quantity (like a number), Lua, etc. Macros get expanded. In the process $\text{T}_{\text{E}}\text{X}$ can enter a group. Inside the group, changes to registers get saved on a stack, and restored after leaving the group. When conditionals are encountered, another kind of nesting happens, and again there is a stack involved. Tokens, expansion, stacks, input levels are all terms used in the next chapters. Don't worry, they lose their magic once you use $\text{T}_{\text{E}}\text{X}$ a lot. You have access to most of the internals and when not, at least it is possible to query some state we're in or level we're at.

When we talk about pack(ing) it can mean two things. When $\text{T}_{\text{E}}\text{X}$ has consumed some tokens that represent text they are added to the current list. When the text is put into a so called `\hbox` (for instance a line in a paragraph) it (normally) first gets hyphenated, next ligatures are built, and finally kerns are added. Each of these stages can be overloaded using Lua code. When these three stages are finished, the dimension of the content is calculated and the box gets its width, height and depth. What happens with the box depends on what macros do with it.

The other thing that can happen is that the text starts a new paragraph. In that case some information is stored in a leading par node. Then indentation is appended and the paragraph ends with some glue. Again the three stages are applied but this time afterwards, the long line is broken into lines and the result is either added to the content of a box or to the main vertical list (the running text so to say). This is called par building. At some point $\text{T}_{\text{E}}\text{X}$ decides that enough is enough and it will trigger the page builder. So, building is another concept we will encounter. Another example of a builder is the one that turns an intermediate math list into something typeset.

Wrapping something in a box is called packing. Adding something to a list is described in terms of contributing. The more complicated processes are wrapped into builders. For now this should be enough to enable you to understand the next chapters. The text is not as enlightening and entertaining as Don Knuth's books, sorry.



2 Differences with LuaTeX

As LuaMetaTeX is a leaner and meaner LuaTeX. This means that substantial parts and dependencies are gone: quite some font code, all backend code with related frontend code and of course image and font inclusion. There is also new functionality which makes for less lean but in the end we still have less, also in terms of dependencies. This chapter will discuss what is gone. We start with the primitives that were dropped.

fonts	<code>\letterspacefont \copyfont \expandglyphsinfont \ignoreligaturesinfont \tagcode \leftghost \rightghost</code>
backend	<code>\dviextension \dvivariable \dvifeedback \pdfextension \pdfvariable \pdffeedback \dviextension \draftmode \outputmode</code>
dimensions	<code>\pageleftoffset \pagerightoffset \pagetopoffset \pagebottomoffset \pageheight \pagewidth</code>
resources	<code>\saveboxresource \useboxresource \lastsavedboxresourceindex \saveimageresource \useimageresource \lastsavedimageresourceindex \lastsavedimageresourcepages</code>
positioning	<code>\savepos \lastxpos \lastypos</code>
directions	<code>\textdir \linedir \mathdir \pardir \pagedir \bodydir \pagedirection \bodydirection</code>
randomizer	<code>\randomseed \setrandomseed \normaldeviate \uniformdeviate</code>
utilities	<code>\synctex</code>
extensions	<code>\latalua \lataluafunction \openout \write \closeout \openin \read \readline \closein \ifeof</code>
control	<code>\suppressfontnotfounderror \suppresslongerror \suppressprimitiveerror \suppressmathparerror \suppressifcsnameerror \suppressoutererror \mathoption</code>
system	<code>\primitive \ifprimitive \formatname</code>
ignored	<code>\long \outer \mag</code>

The resources and positioning primitives are actually useful but can be defined as macros that (via Lua) inject nodes in the input that suit the macro package and backend. The three-letter direction primitives are gone and the numeric variants are now leading. There is no need for page and body related directions and they don't work well in LuaTeX anyway. We only have two directions left. Because we can hook in Lua functions that get information about what is expected (consumer or provider) there are plenty possibilities for adding functionality using this scripting language.

The primitive related extensions were not that useful and reliable so they have been removed. There are some new variants that will be discussed later. The `\outer` and `\long` prefixes are gone as they don't make much sense nowadays and them becoming dummies opened the way to something new: control sequence properties that permit protection against as well as controlled overloading of definitions. I don't think that (ConTeXt) users will notice these prefixes being gone. The definition and parsing related `\suppress..` features are now default and can't be changed so related primitives are gone.

The `\shipout` primitive does no ship out but just erases the content of the box unless of course



that has happened already in another way. A macro package should implement its own backend and related shipout. Talking of backend, the extension primitives that relate to backends can be implemented as part of a backend design using generic whatsits. There is only one type of whatsit now. In fact we're now closer to original T_EX with respect to the extensions.

The `img` library has been removed as it's rather bound to the backend. The `slunicode` library is also gone. There are some helpers in the `string` library that can be used instead and one can write additional Lua code if needed. There is no longer a pdf backend library but we have an up to date pdf parsing library on board.

In the `node`, `tex` and `status` library we no longer have helpers and variables that relate to the backend. The LuaMetaT_EX engine is in principle dvi and pdf unaware. There are, as mentioned, only generic whatsit nodes that can be used for some management related tasks. For instance you can use them to implement user nodes. More extensive status information is provided in the overhauled `status` library. All libraries have additional functionality and names of functions have been normalized (for as far as possible).

The `margin kern` nodes are gone and we now use regular kern nodes for them. As a consequence there are two extra subtypes indicating the injected left or right kern. The `glyph` field served no real purpose so there was no reason for a special kind of node.

The `kpse` library is no longer built-in, but one can use an external `kpse` library, assuming that it is present on the system, because the engine has a so called optional library interface to it. Because there is no backend, quite some file related callbacks could go away. The following file related callbacks remained (till now):

```
find_write_file find_format_file open_data_file
```

The callbacks related to errors are changed:

```
intercept_tex_error intercept_lua_error  
show_error_message show_warning_message
```

There is a hook that gets called when one of the fundamental memory structures gets reallocated.

```
trace_memory
```

When you use the overload protect mechanisms, a callback can be plugged in to handle exceptions:

```
handle_overload
```

The (job) management hooks are kept:

```
process_jobname  
start_run stop_run wrapup_run  
pre_dump  
start_file stop_file
```

Because we use a more generic whatsit model, there is a new callback:

```
show_whatsit
```



Because tracing boxes now reports a lot more information, we have a plug in for detail:

`get_attribute`

Being the core of extensibility, the typesetting callbacks of course stayed. This is what we ended up with:

`append_to_vlist_filter, begin_paragraph, build_page_insert, buildpage_filter, contribute_filter, define_font, find_format_file, find_log_file, get_attribute, glyph_run, handle_overload, hpack_filter, hpack_quality, hyphenate, insert_par, intercept_lua_error, intercept_tex_error, kerning, ligaturing, linebreak_filter, make_extensible, missing_character, mlist_to_hlist, open_data_file, paragraph_context, post_linebreak_filter, pre_dump, pre_linebreak_filter, pre_output_filter, process_jobname, register_extensible, show_error_message, show_lua_call, show_warning_message, show_whatsit, start_file, start_run, stop_file, stop_run, trace_memory, vpack_filter, vpack_quality, wrapup_run`

As in LuaTeX font loading happens with the following callback. This time it really needs to be set because there is no built-in font loader.

`define_font`

There are all kinds of subtle differences in the implementation, for instance we no longer intercept `*` and `&` as these were already replaced long ago in TeX engines by command line options. Talking of options, only a few are left. All input goes via Lua, even the console. One can program a terminal if needed.

We took our time for reaching a stable state in LuaTeX. Among the reasons is the fact that most was experimented with in ConTeXt, which we can adapt to the engine as we go. It took many years to decide what to keep and how to do things. Of course there are places when things can be improved but that most likely only happens in LuaMetaTeX. Contrary to what is sometimes suggested, the LuaTeX-ConTeXt MkIV combination (assuming matched versions) has been quite stable. It made no sense otherwise. Most ConTeXt functionality didn't change much at the user level. Of course there have been issues, as is natural with everything new and beta, but we have a fast update cycle.

The same is true for LuaMetaTeX and ConTeXt LMTX: it can be used for production as usual and in practice ConTeXt users tend to use the beta releases, which proves this. Of course, if you use low level features that are experimental you're on your own. Also, as with LuaTeX it might take many years before a long term stable is defined. The good news is that, when the source code has become part of the ConTeXt distribution, there is always a properly working, more or less long term stable, snapshot.

The error reporting subsystem has been redone quite a bit but is still fundamentally the same. We don't really assume interactive usage but if someone uses it, it might be noticed that it is not possible to backtrack or inject something. Of course it is no big deal to implement all that in Lua if needed. It removes a system dependency and makes for a bit cleaner code. In ConTeXt we quit on an error simply because one has to fix source anyway and runs are fast enough. Logging provides more detail and new primitives can be used to prevent clutter in tracing (the more complex a macro package becomes, the more extreme tracing becomes).



There are new primitives as well as some extensions to existing primitive functionality. These are described in following chapters but there might be hidden treasures in the binary. If you locate them, don't automatically assume them to stay, some might be part of experiments! There are for instance a few `csname` related definers, we have integer and dimension constants, the macro argument parser can be brought in tolerant mode, the repertoire of conditionals has been extended, some internals can be controlled (think of normalization of lines, hyphenation etc.), and macros can be protected against user overload. Not all is discussed in detail in this manual but there are introductions in the ConT_EXt distribution that explain them. But the T_EX kernel is of course omnipresent.

The following primitives are available in LuaT_EX but not in LuaMetaT_EX. Some of these are emulated in ConT_EXt.

<code>automatichyphenmode</code>	<code>lastxpos</code>
<code>bodydir</code>	<code>lastypos</code>
<code>bodydirection</code>	<code>latelua</code>
<code>boxdir</code>	<code>lateluafunction</code>
<code>breakafterdirmode</code>	<code>leftghost</code>
<code>closein</code>	<code>letterspacefont</code>
<code>closeout</code>	<code>linedir</code>
<code>compoundhyphenmode</code>	<code>mag</code>
<code>copyfont</code>	<code>mathdir</code>
<code>draftmode</code>	<code>mathoption</code>
<code>dviextension</code>	<code>nokerns</code>
<code>dvifedback</code>	<code>noligs</code>
<code>dvivariable</code>	<code>nolocaldirs</code>
<code>eTeXVersion</code>	<code>nolocalwhatsits</code>
<code>eTeXglueshrinkorder</code>	<code>normaldeviate</code>
<code>eTeXgluestretchorder</code>	<code>openin</code>
<code>eTeXminorversion</code>	<code>openout</code>
<code>eTeXrevision</code>	<code>outputmode</code>
<code>eTeXversion</code>	<code>pagebottomoffset</code>
<code>expandglyphsinfont</code>	<code>pagedir</code>
<code>fixupboxesmode</code>	<code>pagedirection</code>
<code>glyphdimensionsmode</code>	<code>pageheight</code>
<code>hoffset</code>	<code>pageleftoffset</code>
<code>hyphenationbounds</code>	<code>pagerightoffset</code>
<code>hyphenpenaltymode</code>	<code>pagetopoffset</code>
<code>ifeof</code>	<code>pagewidth</code>
<code>ifprimitive</code>	<code>pardir</code>
<code>ignoreligaturesinfont</code>	<code>pdfextension</code>
<code>immediateassigned</code>	<code>pdffeedback</code>
<code>immediateassignment</code>	<code>pdfvariable</code>
<code>insertht</code>	<code>primitive</code>
<code>lastsavedboxresourceindex</code>	<code>randomseed</code>
<code>lastsavedimageresourceindex</code>	<code>read</code>
<code>lastsavedimageresourcepages</code>	<code>readline</code>



rightghost	suppressprimitiveerror
saveboxresource	synctex
saveimageresource	tagcode
savepos	texdir
setrandomseed	tracingscantokens
shapemode	uniformdeviate
special	useboxresource
suppressfontnotfounderror	useimageresource
suppressifcsnameerror	voffset
suppresslongerror	write
suppressmathparerror	
suppressoutererror	

The following primitives are available in LuaMetaTeX only. At some point in time some might be added to LuaTeX.

UUskewed	Umathstackvariant
UUskewedwithdelims	Umathsubscriptvariant
Uabove	Umathsuperscriptvariant
Uabovewithdelims	Umathtopaccentvariant
Uatop	Umathunderdelimitervariant
Uatopwithdelims	Umathunderlinevariant
Umathaccentbaseheight	Umathvextensiblevariant
Umathaccentvariant	Umathvoid
Umathadapttoleft	Unosubprescript
Umathadapttoright	Unosuperprescript
Umathbotaccentvariant	Uover
Umathclass	Uoverwithdelims
Umathdegreevariant	Ustyle
Umathdelimiterovervariant	Usubprescript
Umathdelimiterundervariant	Usuperprescript
Umathdenominatorvariant	adjustspacingshrink
Umathfractionvariant	adjustspacingstep
Umathhextensiblevariant	adjustspacingstretch
Umathlimits	afterassigned
Umathnoaxis	aftergrouped
Umathnolimits	aliased
Umathnumeratorvariant	atendofgroup
Umathopenupdepth	atendofgrouped
Umathopenupheight	automigrationmode
Umathoverdelimitervariant	beginlocalcontrol
Umathoverlayaccentvariant	beginsimplegroup
Umathoverlinevariant	boxattribute
Umathphantom	boxorientation
Umathradicalvariant	boxtotal
Umathspacebeforeprescript	boxxmove
Umathspacingmode	boxxoffset



boxymove	ifdimval
boxyoffset	ifempty
defcsname	ifflags
dimensiondef	ifhastok
edefcsname	ifhastoks
endsimplegroup	ifhasxtoks
enforced	ifinsert
everytab	ifmathparameter
expand	ifmathstyle
expandafterpars	ifnumval
expandafterspaces	ifparameter
expandcstoken	ifparameters
expandtoken	ifrelax
fontspecifiedname	iftok
fontspecifiedsize	ignorearguments
frozen	ignorepars
futuredef	immutable
futureexpand	insertbox
futureexpandis	insertcopy
futureexpandisap	insertdepth
gdefcsname	insertdistance
gletcsname	insertheight
glettonothing	insertheights
gluespecdef	insertlimit
glyph	insertmode
glyphdatafield	insertmultiplier
glyphoptions	insertprogress
glyphscale	insertunbox
glyphscriptfield	insertuncopy
glyphscriptscale	insertwidth
glyphscriptscriptscale	instance
glyphstatefield	integerdef
glyptextscale	lastarguments
glyphxoffset	lastchkdim
glyphxscale	lastchknum
glyphyoffset	lastnodesubtype
glyphyscale	letcsname
hccode	letfrozen
hyphenationmode	letprotected
ifarguments	lettonothing
ifboolean	linepar
ifchkdim	localcontrol
ifchknum	localcontrolled
ifcmpdim	mathscale
ifcmpnum	meaningfull
ifcstok	meaningless



mugluespecdef	swapcsvalues
mutable	thewithoutunit
noaligned	thewithproperty
norelax	todimension
normalizelinemode	tointeger
numericsscale	tokenized
ordlimits	tolerant
orelse	toscaled
orunless	tracingalignments
overloaded	tracinghyphenation
overloadmode	tracinglevels
overshoot	tracingmath
parametercount	undent
parattr	unhpack
parfillleftskip	unletfrozen
permanent	unletprotected
scaledfontdimen	unvpack
shownodedetails	wrapuppar
snapshotpar	xdefcsname
supmarkmode	

As part of a bit more consistency some function names also changed. Names with an `_` got that removed (as that was the minority). It's easy to provide a back mapping if needed (just alias the functions).

Todo: only mention the LuaTeX ones.

LIBRARY	OLD NAME	NEW NAME	COMMENT
language	clear_patterns	clearpatterns	
	clear_hyphenation	clearhyphenation	
mplib	italcor	italic	
	pen_info	peninfo	
	solve_path	solvepath	
texio	write_nl	writenl	old name stays
node	protect_glyph	protectglyph	
	protect_glyphs	protectglyphs	
	unprotect_glyph	unprotectglyph	
	unprotect_glyphs	unprotectglyphs	
	end_of_math	endofmath	
	mlist_to_hlist	mlisttohlist	
	effective_glue	effectiveglue	
	has_glyph	hasglyph	
	first_glyph	firstglyph	
	has_field	hasfield	
	copy_list	copylist	
	flush_node	flushnode	
flush_list	flushlist		



	insert_before	insertbefore
	insert_after	insertafter
	last_node	lastnode
	is_zero_glue	iszeroglue
	make_extensible	makeextensible
	uses_font	usesfont
	is_char	ischar
	is_direct	isdirect
	is_glyph	isglyph
	is_node	isnode
token	scan_keyword	scankeyword
	scan_keywordcs	scankeywordcs
	scan_int	scanint
	scan_real	scanreal
	scan_float	scanfloat
	scan_dimen	scandimen
	scan_glue	scanglue
	scan_toks	scantoks
	scan_code	scancode
	scan_string	scanstring
	scan_argument	scanargument
	scan_word	scanword
	scan_csname	scancsname
	scan_list	scanlist
	scan_box	scanbox

It's all part of trying to make the code base consistent but it is sometimes a bit annoying. However, that's why we develop this engine independent of the LuaTeX code base. It's anyway a change that has been on my todo list for quite a while because those inconsistencies annoyed me.



3 The original engines

3.1 The merged engines

3.1.1 The rationale

The first version of Lua \TeX , made by Hartmut after we discussed the possibility of an extension language, only had a few extra primitives and it was largely the same as pdf \TeX . It was presented to the public in 2005. As part of the Oriental \TeX project, Taco merged some parts of Aleph into the code and some more primitives were added. Then we started more fundamental experiments. After many years, when the engine had become more stable, the decision was made to clean up the rather hybrid nature of the program. This means that some primitives were promoted to core primitives, often with a different name, and that others were removed. This also made it possible to start cleaning up the code base, which showed decades of stepwise additions to original \TeX . In chapter 5 we discuss some new primitives, here we will cover most of the adapted ones.

During more than a decade stepwise new functionality was added and after 10 years the more or less stable version 1.0 was presented. But we continued and after some 15 years the LuaMeta \TeX follow up entered its first testing stage. But before details about the engine are discussed in successive chapters, we first summarize where we started from. Keep in mind that in LuaMeta \TeX we have a bit less than in Lua \TeX , so this section differs from the one in the Lua \TeX manual.

Besides the expected changes caused by new functionality, there are a number of not-so-expected changes. These are sometimes a side-effect of a new (conflicting) feature, or, more often than not, a change necessary to clean up the internal interfaces. These will also be mentioned.

Again we stress that *this is not a \TeX manual, nor a tutorial*. If you are unfamiliar with \TeX first play a little with a macro package, take a look at the \TeX book, make yourself familiar with the concepts and macro language. That will likely take days and not hours. Also, many of the new concepts introduced in Lua \TeX and LuaMeta \TeX are explained in documents that come with the Con \TeX t distribution, articles and presentations. It doesn't pay off to repeat that here, especially not in a time when users often search instead of read from cover to cover.

3.1.2 Changes from \TeX 3.1415926...

Of course it all starts with traditional \TeX . Even if we started with pdf \TeX , most still comes from original Knuthian \TeX . But we divert a bit.

- ▶ The current code base is written in C, not Pascal. The original web documentation is kept when possible and not wrapped in tagged comments. As a consequence instead of one large file plus change files, we now have multiple files organized in categories like `tex`, `lua`, `languages`, `fonts`, `libraries`, etc. There are some artifacts of the conversion to C, but these got (and get) removed stepwise. The documentation, which actually comes from the mix of engines (via so called change files), is a mix of what authors of the engines wove into the source, and most is of course from Don Knuth's original. In LuaMeta \TeX we try to stay as



close as possible to the original so that the documentation of the fundamentals behind T_EX by Don Knuth still applies. However, because we use C, some documentation is a bit off. Also, most global variables are now collected in structures, but the original names and level of abstraction were mostly kept. On the other hand, opening up had its impact on the code, so that makes some documentation a bit off too. Adapting that all will take time.

- ▶ See chapter 7 for many small changes related to paragraph building, language handling and hyphenation. The most important change is that adding a brace group in the middle of a word (like in `of{ }fice`) does not prevent ligature creation. Also, the hyphenation, ligature building and kerning has been split so that we can hook in alternative or extra code wherever we like. There are various options to control discretionary injection and related penalties are now integrated in these nodes. Language information is now bound to glyphs. The number of languages in LuaMetaT_EX is smaller than in LuaT_EX. Control over discretionaries is more granular and now managed by less variables.
- ▶ There is no pool file, all strings are embedded during compilation. This also removed some memory constraints. We kept token and node memory management because it is convenient and efficient but parts were reimplemented in order to remove some constraints. Token memory management is largely the same. All the other large memory structures, like those related to nesting, the save stack, input levels, the hash table and table of equivalents, etc. now all start out small and are enlarged when needed, where maxima are controlled in the usual way. In principle the initial memory footprint is smaller while at the same time we can go real large. Because we have wide memory words some data (arrays) used for housekeeping could be reorganized a bit.
- ▶ The specifier `plus 1 filllll` does not generate an error. The extra 'l' is simply typeset.
- ▶ The upper limit to `\endlinechar` and `\newlinechar` is 127.
- ▶ Because the backend is not built-in, the magnification (`\mag`) primitive is gone. A `shipout` just discards the content of the given box. The write related primitives have to be implemented in the used macro package using Lua. None of the pdfT_EX derived primitives is present.
- ▶ Because there is no font loader, a Lua variant is free to either support or not the Omega `ofm` file format. As there are hardly any such fonts it probably makes no sense. There is plenty of control over the way glyphs get treated and scaling of fonts and glyphs is also more dynamic.
- ▶ There is more control over some (formerly hard-coded) math properties. In fact, there is a whole extra bit of math related code because we need to deal with OpenType fonts. The math processing has been adapted to the new (dynamic) font and glyph scaling features.
- ▶ The `\outer` and `\long` prefixed are silently ignored. It is permitted to use `\par` in math.
- ▶ The lack of a backend means that some primitives related to it are not implemented. This is no big deal because it is possible to use the scanner library to implement them as needed, which depends on the macro package and backend.
- ▶ The math style related primitives can use numbers as well as symbolic names. There is some more (control over) math anyway, which is a side effect of supporting OpenType math.

3.1.3 Changes from ε -T_EX 2.2

Being the de-facto standard extension of course we provide the ε -T_EX features, but with a few small adaptations.

- ▶ The ε -T_EX functionality is always present and enabled so the prepended asterisk or `-etex`



switch for `iniTeX` is not needed.

- ▶ The `TeXXeT` extension is not present, so the primitives `\TeXXeTstate`, `\beginR`, `\beginL`, `\endR` and `\endL` are missing. Instead we used the Omega/Aleph approach to directionality as starting point, albeit it has been changed quite a bit, so that we're probably not that far from `TeXXeT`.
- ▶ Some of the tracing information that is output by ε -TeX's `\tracingassigns` and `\tracingrestores` is not there. Also keep in mind that tracing doesn't involve what Lua does.
- ▶ Register management in `LuaMetaTeX` uses the Omega/Aleph model, so the maximum value is 65535 and the implementation uses a flat array instead of the mixed flat & sparse model from ε -TeX.
- ▶ Because we have more nodes, conditionals, etc. the ε -TeX status related variables are adapted to `LuaMetaTeX`: we use different 'constants', but that should be no problem because any sane macro package uses abstraction.
- ▶ The `\scantokens` primitive is now using the same mechanism as Lua print-to-TeX uses, which simplifies the code. There is a little performance hit but it will not be noticed in `ConTeXt`, because we never use this primitive.
- ▶ Because we don't use change files on top of original TeX, the integration of ε -TeX functionality is bit more natural, code wise.
- ▶ The `\readline` primitive has to be implemented in Lua. This is a side effect of delegating all file io.
- ▶ Most of the code is rewritten but the original primitives are still tagged as coming from ε -TeX.

3.1.4 Changes from pdfTeX 1.40

Because we want to produce pdf the most natural starting point was the popular pdfTeX program. We inherit the stable features, dropped most of the experimental code and promoted some functionality to core LuaTeX functionality which in turn triggered renaming primitives. However, as the backend was dropped, not that much from pdfTeX is present any more. Basically all we now inherit from pdfTeX is expansion and protrusion but even that has been adapted. So don't expect `LuaMetaTeX` to be compatible.

- ▶ The experimental primitives `\ifabsnum` and `\ifabsdim` have been promoted to core primitives.
- ▶ The primitives `\ifincsname`, `\expanded` and `\quitvmode` have become core primitives.
- ▶ As the hz (expansion) and protrusion mechanism are part of the core the related primitives `\lrcode`, `\rrcode`, `\efcode`, `\leftmarginkern`, `\rightmarginkern` are promoted to core primitives. The two commands `\protrudechars` and `\adjustspacing` control these processes.
- ▶ In `LuaMetaTeX` three extra primitives can be used to overload the font specific settings: `\adjustspacingstep` (max: 100), `\adjustspacingstretch` (max: 1000) and `\adjustspacingshrink` (max: 500).
- ▶ The hz optimization code has been partially redone so that we no longer need to create extra font instances. The front- and backend have been decoupled and the glyph and kern nodes carry the used values. In `LuaTeX` that made a more efficient generation of pdf code possible. It also resulted in much cleaner code. The backend code is gone, but of course the information is still carried around.



- ▶ When `\adjustspacing` has value 2, hz optimization will be applied to glyphs and kerns. When the value is 3, only glyphs will be treated. A value smaller than 2 disables this feature.
- ▶ When `\protrudechars` has a value larger than zero characters at the edge of a line can be made to hang out. A value of 2 will take the protrusion into account when breaking a paragraph into lines. A value of 3 will try to deal with right-to-left rendering; this is a still experimental feature.
- ▶ The pixel multiplier dimension `\pxdimen` has been inherited as core primitive.
- ▶ The primitive `\tracingfonts` is now a core primitive but doesn't relate to the backend.

3.1.5 Changes from Aleph RC4

In LuaTeX we took the 32 bit aspects and much of the directional mechanisms and merged it into the pdfTeX code base as starting point for further development. Then we simplified directionality, fixed it and opened it up. In LuaMetaTeX not that much of the later is left. We only have two horizontal directions. Instead of vertical directions we introduce an orientation model bound to boxes.

The already reduced-to-four set of directions now only has two members: left-to-right and right-to-left. They don't do much as it is the backend that has to deal with them. When paragraphs are constructed a change in horizontal direction is irrelevant for calculating the dimensions. So, basically most that we do is registering state and passing that on till the backend can do something with it.

Here is a summary of inherited functionality:

- ▶ The `^^` notation has been extended: after `^^^^` four hexadecimal characters are expected and after `^^^^^^` six hexadecimal characters have to be given. The original TeX interpretation is still valid for the `^^` case but the four and six variants do no backtracking, i.e. when they are not followed by the right number of hexadecimal digits they issue an error message. Because `^^` is a normal TeX case, we don't support the odd number of `^^^^` either.
- ▶ Glues *immediately after* direction change commands are not legal breakpoints. There is a bit more sanity testing for the direction state. This can be configured.
- ▶ The placement of math formula numbers is direction aware and adapts accordingly. Boxes carry directional information but rules don't.
- ▶ There are no direction related primitives for page and body directions. The paragraph, text and math directions are specified using primitives that take a number. The three letter codes are dropped.

3.1.6 Changes from standard web2c

The LuaMetaTeX codebase is not dependent on the web2c framework. The interaction with the file system and tds is up to Lua. There still might be traces but eventually the code base should be lean and mean. The MetaPost library is coded in cweb and in order to be independent from related tools, conversion to C is done with a Lua script ran by, surprise, LuaMetaTeX.



3.2 Implementation notes

3.2.1 Memory allocation

The single internal memory heap that traditional T_EX used for tokens and nodes is split into two separate arrays. Each of these will grow dynamically when needed. Internally a token or node is an index into these arrays. This permits for an efficient implementation and is also responsible for the performance of the core. All other data structures are mostly the same but managed dynamically too. Because we operate in a 64 bit world, the parallel table of equivalents needed for managing levels, is gone. Anyhow, the original documentation in T_EX The Program mostly applies!

3.2.2 Sparse arrays

The `\mathcode`, `\delcode`, `\catcode`, `\sfcode`, `\lccode` and `\uccode` (and the new `\hjcode`) tables are now sparse arrays that are implemented in C. They are no longer part of the T_EX ‘equivalence table’ and because each had 1.1 million entries with a few memory words each, this makes a major difference in memory usage. Performance is not really hurt by this.

The `\catcode`, `\sfcode`, `\lccode`, `\uccode` and `\hjcode` assignments don't show up when using the ε -T_EX tracing routines `\tracingassigns` and `\tracingrestores` but we don't see that as a real limitation. It also saves a lot of clutter.

The glyph ids within a font are also managed by means of a sparse array as glyph ids can go up to index $2^{21} - 1$ but these are never accessed directly so again users will not notice this.

3.2.3 Simple single-character csnames

Single-character commands are no longer treated specially in the internals, they are stored in the hash just like the multiletter control sequences. This is a side effect of going Unicode and utf. Where using 256 slots in an array add no burden supporting the whole Unicode range is a waste of space. Therefore, also active characters are internally implemented as a special type of multi-letter control sequences that uses a prefix that is otherwise impossible to obtain.

The code that displays control sequences explicitly checks if the length is one when it has to decide whether or not to add a trailing space.

3.2.4 Binary file reading

All input now goes via Lua: files loaded with `\input` as well as files that are opened with `\openin`. Actually the later has to be implemented in terms of macros and Lua calls. This also means that compared to LuaT_EX the internal handling of input has been changed but users won't notice that.

Setting a callback is expected now. Although reading input natively using `getc` calls is more efficient, we now fetch lines from Lua, put them in a buffer and then pick successive bytes (keep in mind that we read utf) from that. The performance is quite ok, also because Lua is fast, todays



operating systems cache, and storage media have become very fast. Also, T_EX is spending more time messing around with what it has input than actually reading input.

3.2.5 Tabs and spaces

We conform to the way other T_EX engines handle trailing tabs and spaces. For decades trailing tabs and spaces (before a newline) were removed from the input but this behaviour was changed in September 2017 to only handle spaces. We are aware that this can introduce compatibility issues in existing workflows but because we don't want too many differences with upstream T_EXLive we just follow up on that patch (which is a functional one and not really a fix). It is up to macro packages maintainers to deal with possible compatibility issues and in LuaMetaT_EX they can do so via the callbacks that deal with reading from files.

The previous behaviour was a known side effect and (as that kind of input normally comes from generated sources) it was normally dealt with by adding a comment token to the line in case the spaces and/or tabs were intentional and to be kept. We are aware of the fact that this contradicts some of our other choices but consistency with other engines. We still stick to our view that at the log level we can (and might be) more incompatible. We already expose some more details anyway.

3.2.6 Logging

When detailed logging is enabled more detail is output with respect to what nodes are involved. This is a side effect of the core nodes having more detailed subtype information. The benefit of more detail wins from any wish to be byte compatible in the logging. One can always write additional logging in Lua.

The information that goes into the log file can be different from LuaT_EX, and might even differ a bit more in the future. The main reason is that inside the engine we have more granularity, which for instance means that we output subtype and attribute related information when nodes are printed. Of course we could have offered a compatibility mode but it serves no purpose. Over time there have been many subtle changes to control logs in the T_EX ecosystems so another one is bearable.

In a similar fashion, there is a bit different behaviour when T_EX expects input, which in turn is a side effect of removing the interception of * and & which made for cleaner code (quite a bit had accumulated as side effect of continuous adaptations in the T_EX ecosystems). There was already code that was never executed, simply as side effect of the way LuaT_EX initializes itself (one needs to enable classes of primitives for instance). Keep in mind that over time system dependencies have been handles with T_EX change files, the web2c infrastructure, kpse features, compilation variables and flags, etc. In LuaMetaT_EX we try to minimize all that.

3.2.7 Parsing

Token parsers have been upgraded for the sake of Lua, \csname handling has been extended, macro definitions can be more flexible so there code was adapted, more conditionals also brought some changes. But we build upon the (reorganized) T_EX foundation so the basics can definitely



be recognized.

Because of interfacing in Lua the internal token and node organization has been normalized (read: we cannot cheat because all is kind of visible). On the one hand this can come with a performance penalty but that is more than compensated by extensions, optimized parsers and such. Still the fact that we are utf based (32 bit) makes the machinery slower than the 8 bit original. The reworked LuaMetaT_EX engine is substantially faster than the LuaT_EX predecessor.

The handling of conditionals has been adapted so that we can have flatter branches (`\orelse cum suis`). This again has some consequences for parsing. Because parsing alignments is rather interwoven in general parsing and expansion the handling of related primitives has been slightly adapted (also for the sake of Lua interfacing) and dealing with `\noalign` situations is a bit more convenient.

This are just a few of the adaptations and most of this happened stepwise with testing in the ConT_EXt code base. It will be clear that LuaMetaT_EX is a quite different extension to the original. You're warned.





4 Using LuaMetaTeX

4.1 Initialization

4.1.1 LuaMetaTeX as a Lua interpreter

Although LuaMetaTeX is primarily meant as a TeX engine, it can also serve as a stand alone Lua interpreter. There are two ways to make LuaMetaTeX behave like a standalone Lua interpreter:

- ▶ if a `--luaonly` option is given on the commandline, or
- ▶ if the only non-option argument (file) on the commandline has the extension `lua` or `luc`.

In this mode, it will set Lua's `arg[0]` to the found script name, pushing preceding options in negative values and the rest of the command line in the positive values, just like the Lua interpreter does.

LuaMetaTeX will exit immediately after executing the specified Lua script and is, in effect, a somewhat bulky stand alone Lua interpreter with a bunch of extra preloaded libraries. But we really want to keep the binary small, if possible below the 3MB which is okay for a script engine.

When no argument is given, LuaMetaTeX will look for a Lua file with the same name as the binary and run that one when present. This makes it possible to use the engine as a stub. For instance, in ConTeXt a symlink from `mtxrun` to type `luametatex` will run the `mtxrun.lua` script when present in the same path as the binary itself

4.1.2 Other commandline processing

When the LuaMetaTeX executable starts, it looks for the `--lua` command line option. If there is no `--lua` option, the command line is interpreted in a similar fashion as the other TeX engines. All options are accepted but only some are understood by LuaMetaTeX itself:

COMMANDLINE ARGUMENT	EXPLANATION
<code>--credits</code>	display credits and exit
<code>--fmt=FORMAT</code>	load the format file FORMAT
<code>--help</code>	display help and exit
<code>--ini</code>	be <code>iniluatex</code> , for dumping formats
<code>--jobname=STRING</code>	set the job name to STRING
<code>--lua=FILE</code>	load and execute a Lua initialization script
<code>--version</code>	display version and exit

There are less options than with LuaTeX, because one has to deal with them in Lua anyway. There are no options to enter a safer mode or control executing programs. This can easily be achieved with a startup Lua script.

Next the initialization script is loaded and executed. From within the script, the entire command line is available in the Lua table `arg`, beginning with `arg[0]`, containing the name of the



executable. As consequence warnings about unrecognized options are suppressed.

Command line processing happens very early on. So early, in fact, that none of \TeX 's initializations have taken place yet. The Lua libraries that don't deal with \TeX are initialized early.

LuaMeta \TeX allows some of the command line options to be overridden by reading values from the `texconfig` table at the end of script execution (see the description of the `texconfig` table later on in this document for more details on which ones exactly).

The value to use for `\jobname` is decided as follows:

- ▶ If `--jobname` is given on the command line, its argument will be the value for `\jobname`, without any changes. The argument will not be used for actual input so it need not exist. The `--jobname` switch only controls the `\jobname` setting.
- ▶ Otherwise, `\jobname` will be the name of the first file that is read from the file system, with any path components and the last extension (the part following the last `.`) stripped off.
- ▶ There is an exception to the previous point: if the command line goes into interactive mode (by starting with a command) and there are no files input via `\everyjob` either, then the `\jobname` is set to `texput` as a last resort.

So let's summarize this. The handling of what is called `jobname` is a bit complex. There can be explicit names set on the command line but when not set they can be taken from the `texconfig` table.

```
startup filename    -lua      a Lua file
startup jobname     -jobname  a  $\TeX$  tex      texconfig.jobname
startup dumpname    -fmt      a format file texconfig.formatname
```

These names are initialized according to `--luaonly` or the first filename seen in the list of options. Special treatment of `&` and `*` as well as interactive startup is gone but we still enter \TeX via an forced `\input` into the input buffer.¹

When we are in \TeX mode at some point the engine needs a filename, for instance for opening a log file. At that moment the set `jobname` becomes the internal one and when it has not been set which internalized to `jobname` but when not set becomes `texput`. When you see a `texput.log` file someplace on your system it normally indicates a bad run.

When running on MS Windows the command line, filenames, environment variable access etc. internally uses the current code page but to the user is exposed as `utf8`. Normally users won't notice this.

There is an extra options `--permitloadlib` that needs to be given when you load external libraries via Lua. Although you could manage this via Lua itself in a startup script, the reason for having this as option is the wish for security (at some point that became a demand for Lua \TeX), so this might give an extra feeling of protection.

¹ This might change at some point into an explicit loading triggered via Lua.



4.2 Lua behaviour

4.2.1 The Lua version

We currently use Lua 5.4 and will follow developments of the language but normally with some delay. Therefore the user needs to keep an eye on (subtle) differences in successive versions of the language. Here is an example of one aspect.

Luas `tostring` function (and `string.format`) may return values in scientific notation, thereby confusing the \TeX end of things when it is used as the right-hand side of an assignment to a `\dimen` or `\count`. The output of these serializers also depend on the Lua version, so in Lua 5.3 you can get different output than from 5.2. It is best not to depend the automatic cast from string to number and vice versa as this can change in future versions.

4.2.2 Locales

In stock Lua, many things depend on the current locale. In $\text{LuaMeta}\TeX$, we can't do that, because it makes documents unportable. While $\text{LuaMeta}\TeX$ is running it forces the following locale settings:

```
LC_CTYPE=C
LC_COLLATE=C
LC_NUMERIC=C
```

There is no way to change that as it would interfere badly with the often language specific conversions needed at the \TeX end.

4.3 Lua modules

Of course the regular Lua modules are present. In addition we provide the `lpeg` library by Roberto Ierusalimsky. This library is not Unicode-aware, but interprets strings on a byte-per-byte basis. This mainly means that `lpeg.S` cannot be used with utf8 characters that need more than one byte, and thus `lpeg.S` will look for one of those two bytes when matching, not the combination of the two. The same is true for `lpeg.R`, although the latter will display an error message if used with multibyte characters. Therefore `lpeg.R('ää')` results in the message `bad argument #1 to 'R' (range must have two characters)`, since to `lpeg`, `ä` is two 'characters' (bytes), so `ää` totals three. In practice this is no real issue and with some care you can deal with Unicode just fine.

There are some more libraries present. These are discussed on a later chapter. For instance we embed `luasocket` but contrary to $\text{Lua}\TeX$ don't embed the related Lua code. An adapted version of `luafilesystem` is also included. There are more extensive math libraries and there are libraries that deal with encryption and compression. At some point some of these might become so called optional libraries (read: the handful that we provide interfaces for but that get loaded on demand).



4.4 Testing

For development reasons you can influence the used startup date and time. By setting the `start_time` variable in the `texconfig` table; as with other variables we use the internal name there. When Universal Time is needed, set the entry `use_utc_time` in the `texconfig` table.

In ConT_EXt we provide the command line argument `--nodates` that does a bit more than disabling dates; it avoids time dependent information in the output file for instance.



5 Basic T_EX enhancements

5.1 Introduction

5.1.1 Primitive behaviour

From day one, LuaT_EX has offered extra features compared to the superset of pdfT_EX, which includes ε -T_EX, and Aleph. This has not been limited to the possibility to execute Lua code via `\directlua`, but LuaT_EX also adds functionality via new T_EX-side primitives or extensions to existing ones. The same is true for LuaMetaT_EX. Some primitives have `luatex` in their name and there will be no `luametateX` variants. This is because we consider LuaMetaT_EX to be LuaT_EX2⁺. Contrary to the LuaT_EX engine LuaMetaT_EX enables all its primitives. You can clone (a selection of) primitives with a different prefix, like this:

```
\directlua { tex.enableprimitives('normal',tex.extraprimtives()) }
```

The `extraprimtives` function returns the whole list or a subset, specified by one or more keywords `core`, `tex`, `etex` or `luatex`. When you clone all primitives you can also do this:

```
\directlua { tex.enableprimitives('normal',true) }
```

But be aware that the curly braces may not have the proper `\catcode` assigned to them at this early time (giving a ‘Missing number’ error), so it may be needed to put these assignments before the above line:

```
\catcode `{\ = 1  
\catcode `}\ = 2
```

More fine-grained primitives control is possible and you can look up the details in section 11.3.15. There are only three kinds of primitives: `tex`, `etex` and `luatex` but a future version might drop this and no longer make that distinction as it no longer serves a purpose apart from the fact that it reveals some history.

5.1.2 Version information

5.1.2.1 `\luatexbanner`, `\luatexversion` and `\luatexrevision`

There are three primitives to test the version of LuaT_EX (and LuaMetaT_EX):

PRIMITIVE	VALUE	EXPLANATION
<code>\luatexbanner</code>	This is LuaMetaTeX, Version 2.09.14	the banner reported on the console
<code>\luatexversion</code>	209	major and minor number combined
<code>\luatexrevision</code>	14	the revision number

A version is defined as follows:



- ▶ The major version is the integer result of `\luatexversion` divided by 100. The primitive is an ‘internal variable’, so you may need to prefix its use with `\the` or `\number` depending on the context.
- ▶ The minor version is a number running from 0 upto 99.
- ▶ The revision is reported by `\luatexrevision`. Contrary to other engines in LuaMetaT_EX is also a number so one needs to prefix it with `\the` or `\number`.²
- ▶ The full version number consists of the major version (X), minor version (YY) and revision (ZZ), separated by dots, so X.YY.ZZ.

The LuaMetaT_EX version number starts at 2 in order to prevent a clash with LuaT_EX, and the version commands are the same. This is a way to indicate that these projects are related.

5.2 Unicode text support

5.2.1 Extended ranges

Text input and output is now considered to be Unicode text, so input characters can use the full range of Unicode ($2^{20} + 2^{16} - 1 = 0x10FFFF$). Later chapters will talk of characters and glyphs. Although these are not interchangeable, they are closely related. During typesetting, a character is always converted to a suitable graphic representation of that character in a specific font. However, while processing a list of to-be-typeset nodes, its contents may still be seen as a character. Inside the engine there is no clear separation between the two concepts. Because the subtype of a glyph node can be changed in Lua it is up to the user. Subtypes larger than 255 indicate that font processing has happened.

A few primitives are affected by this, all in a similar fashion: each of them has to accommodate for a larger range of acceptable numbers. For instance, `\char` now accepts values between 0 and 1,114,111. This should not be a problem for well-behaved input files, but it could create incompatibilities for input that would have generated an error when processed by older T_EX-based engines. The affected commands with an altered initial (left of the equal sign) or secondary (right of the equal sign) value are: `\char`, `\lccode`, `\uccode`, `\hjcode`, `\catcode`, `\sfcode`, `\efcode`, `\lpcode`, `\rprcode`, `\chardef`.

As far as the core engine is concerned, all input and output to text files is utf-8 encoded. Input files can be pre-processed using the reader callback. This will be explained in section ???. Normalization of the Unicode input is on purpose not built-in and can be handled by a macro package during callback processing. We have made some practical choices and the user has to live with those.

Output in byte-sized chunks can be achieved by using characters just outside of the valid Unicode range, starting at the value 1,114,112 (0x110000). When the time comes to print a character $c \geq 1,114,112$, LuaT_EX will actually print the single byte corresponding to c minus 1,114,112.

Contrary to other T_EX engines, the output to the terminal is as-is so there is no escaping with `^^`.

² In the past it always was good to prefix the revision with `\number` anyway, just to play safe, although there have for instance been times that pdfT_EX had funny revision indicators that at some point ended up as letters due to the internal conversions.



We operate in a utf universe. Because we operate in a C universum, zero characters are special but because we also live in a Unicode galaxy that is no real problem.

5.2.2 `\Uchar`

The expandable command `\Uchar` reads a number between 0 and 1,114,111 and expands to the associated Unicode character.

5.2.3 Extended tables

All traditional \TeX and $\varepsilon\text{-}\TeX$ registers can be 16-bit numbers. The affected commands are:

<code>\count</code>	<code>\countdef</code>	<code>\box</code>	<code>\wd</code>
<code>\dimen</code>	<code>\dimendef</code>	<code>\unhbox</code>	<code>\ht</code>
<code>\skip</code>	<code>\skipdef</code>	<code>\unvbox</code>	<code>\dp</code>
<code>\muskip</code>	<code>\muskipdef</code>	<code>\copy</code>	<code>\setbox</code>
<code>\marks</code>	<code>\toksdef</code>	<code>\unhcopy</code>	<code>\vsplit</code>
<code>\toks</code>	<code>\insert</code>	<code>\unvcopy</code>	

Fonts are loaded via Lua and a minimal amount of information is kept at the \TeX end. Sharing resources is up to the loaders. The engine doesn't really care about what a character (or glyph) number represents (a Unicode or index) as it only is interested in dimensions.

In \TeX the number of registers is 256 and $\varepsilon\text{-}\TeX$ bumped that to 32K. One reason for a fixed number is that these registers are fast ways to store data and therefore are part of the main lookup table (used for data and pointers to data as well as save and restore housekeeping). In $\text{Lua}\TeX$ the number was bumped to 64K but one can argue that less would also do. In order to keep the default memory footprint reasonable, in $\text{LuaMeta}\TeX$ the number of languages, fonts and marks is limited. The size of some tables can be limited by configuration settings, so they can start out small and grow till configured maximum which is smaller than the absolute maximum. The following table shows all kind of defaults as reported by `status.getconstants()`.

<code>awful_bad</code>	1073741823
<code>decent_criterium</code>	12
<code>default_catcode_table</code>	-1
<code>default_deadcycles</code>	25
<code>default_eqno_gap_step</code>	1000
<code>default_hangafter</code>	1
<code>default_output_box</code>	255
<code>default_pre_display_gap</code>	2000
<code>default_rule</code>	26214
<code>default_space_factor</code>	1000
<code>default_tolerance</code>	10000
<code>deplorable</code>	100000
<code>eject_penalty</code>	-10000
<code>ignore_depth</code>	-65536000



infinite_bad	10000
infinite_penalty	10000
infinity	2147483647
large_width_excess	7230584
loose_criterium	99
max_bytecode_index	65535
max_cardinal	-1
max_category_code	15
max_char_code	15
max_character_code	1114111
max_data_value	2097151
max_dimen	1073741823
max_function_reference	2097151
max_half_value	32767
max_halfword	1073741823
max_integer	2147483647
max_mark_index	9999
max_math_class_code	7
max_math_family_index	255
max_n_of_bytecodes	65536
max_n_of_catcode_tables	256
max_n_of_fonts	100000
max_n_of_languages	10000
max_n_of_marks	10000
max_n_of_math_families	256
max_n_of_registers	65536
max_newline_character	127
max_quarterword	65535
max_register_index	65535
max_size_of_word	1024
max_space_factor	32767
min_cardinal	0
min_data_value	0
min_dimen	-1073741823
min_halfword	-1073741823
min_infinity	-2147483647
min_integer	-2147483647
min_quarterword	0
min_space_factor	0
no_catcode_table	-2
null	0
null_flag	-1073741824
null_font	0
one_bp	65781
preset_rule_thickness	1073741824
small_stretchability	1663497



tex_eqtb_size	590032
tex_hash_prime	131041
tex_hash_size	131072
two	131072
unity	65536
unused_attribute_value	-2147483647
unused_script_value	0
unused_state_value	0
zero_glue	0

Because we have additional ways to store integers, dimensions and glue, we might actually decide to decrease the maximum of the registers: if 64K is not enough, and you work around it, then likely 32K might do as well. Also, we have Lua to store massive amounts of data. One can argue that saving some 1.5MB memory (when we go halfway) is not worth the effort in a time when you have to close a browser in order to free the gigabytes it consumes, but there is no reason not to be lean and mean: a more conservative approach to start with creates headroom for going wild later.

5.3 Attributes

5.3.1 Nodes

When $\text{T}_{\text{E}}\text{X}$ reads input it will interpret the stream according to the properties of the characters. Some signal a macro name and trigger expansion, others open and close groups, trigger math mode, etc. What's left over becomes the typeset text. Internally we get a linked list of nodes. Characters become glyph nodes that have for instance a font and char property and $\backslash\text{kern } 10\text{pt}$ becomes a kern node with a width property. Spaces are alien to $\text{T}_{\text{E}}\text{X}$ as they are turned into glue nodes. So, a simple paragraph is mostly a mix of sequences of glyph nodes (words) and glue nodes (spaces). A node can have a subtype so that it can be recognized as for instance a space related glue.

The sequences of characters at some point are extended with disc nodes that relate to hyphenation. After that font logic can be applied and we get a list where some characters can be replaced, for instance multiple characters can become one ligature, and font kerns can be injected. This is driven by the font properties.

Boxes (like $\backslash\text{hbox}$ and $\backslash\text{vbox}$) become hlist or vlist nodes with width, height, depth and shift properties and a pointer list to its actual content. Boxes can be constructed explicitly or can be the result of subprocesses. For instance, when lines are broken into paragraphs, the lines are a linked list of hlist nodes, possibly with glue and penalties in between.

Internally nodes have a number. This number is actually an index in the memory used to store nodes.

So, to summarize: all that you enter as content eventually becomes a node, often as part of a (nested) list structure. They have a relative small memory footprint and carry only the minimal amount of information needed. In traditional $\text{T}_{\text{E}}\text{X}$ a character node only held the font and slot number, in $\text{LuaT}_{\text{E}}\text{X}$ we also store some language related information, the expansion factor, etc.



Now that we have access to these nodes from Lua it makes sense to be able to carry more information with a node and this is where attributes kick in.

It is important to keep in mind that there are situations where nodes get created in the current context. For instance, when \TeX builds a paragraph or page or constructs math formulas, it does add nodes and giving these the current attributes makes no sense and can even give weird side effects. In these cases, the attributes are inherited from neighbouring nodes.

5.3.2 Attribute registers

Attributes are a completely new concept in Lua \TeX . Syntactically, they behave a lot like counters: attributes obey \TeX 's nesting stack and can be used after `\the` etc. just like the normal `\count` registers.

```
\attribute <16-bit number> <optional equals> <32-bit number>
\attributedef <cname> <optional equals> <16-bit number>
```

Conceptually, an attribute is either ‘set’ or ‘unset’. Unset attributes have a special negative value to indicate that they are unset, that value is the lowest legal value: `-7FFFFFFF` in hexadecimal, a.k.a. `-2147483647` in decimal. It follows that the value `-7FFFFFFF` cannot be used as a legal attribute value, but you *can* assign `-7FFFFFFF` to ‘unset’ an attribute. All attributes start out in this ‘unset’ state in `ini \TeX` .

Attributes can be used as extra counter values, but their usefulness comes mostly from the fact that the numbers and values of all ‘set’ attributes are attached to all nodes created in their scope. These can then be queried from any Lua code that deals with node processing. Further information about how to use attributes for node list processing from Lua is given in chapter 9.

Attributes are stored in a sorted (sparse) linked list that are shared when possible. This permits efficient testing and updating. You can define many thousands of attributes but normally such a large number makes no sense and is also not that efficient because each node carries a (possibly shared) link to a list of currently set attributes. But they are a convenient extension and one of the first extensions we implemented in Lua \TeX .

In LuaMeta \TeX we try to minimize the memory footprint and creation of these attribute lists more aggressive sharing them. This feature is still somewhat experimental.

5.3.3 Box attributes

Nodes typically receive the list of attributes that is in effect when they are created. This moment can be quite asynchronous. For example: in paragraph building, the individual line boxes are created after the `\par` command has been processed, so they will receive the list of attributes that is in effect then, not the attributes that were in effect in, say, the first or third line of the paragraph.

Similar situations happen in Lua \TeX regularly. A few of the more obvious problematic cases are dealt with: the attributes for nodes that are created during hyphenation, kerning and ligaturing borrow their attributes from their surrounding glyphs, and it is possible to influence box attributes directly.

When you assemble a box in a register, the attributes of the nodes contained in the box are unchanged when such a box is placed, unboxed, or copied. In this respect attributes act the



same as characters that have been converted to references to glyphs in fonts. For instance, when you use attributes to implement color support, each node carries information about its eventual color. In that case, unless you implement mechanisms that deal with it, applying a color to already boxed material will have no effect. Keep in mind that this incompatibility is mostly due to the fact that separate specials and literals are a more unnatural approach to colors than attributes.

It is possible to fine-tune the list of attributes that are applied to a `hbox`, `vbox` or `vtop` by the use of the keyword `attr`. The `attr` keyword(s) should come before a `to` or `spread`, if that is also specified. An example is:

```
\attribute997=123
\attribute998=456
\setbox0=\hbox {Hello}
\setbox2=\hbox attr 999 = 789 attr 998 = -"7FFFFFFF{Hello}
```

Box 0 now has attributes 997 and 998 set while box 2 has attributes 997 and 999 set while the nodes inside that box will all have attributes 997 and 998 set. Assigning the maximum negative value causes an attribute to be ignored.

To give you an idea of what this means at the Lua end, take the following code:

```
for b=0,2,2 do
  for a=997, 999 do
    tex.sprint("box ", b, " : attr ",a," : ",tostring(tex.box[b] [a]))
    tex.sprint("\quad\quad")
    tex.sprint("list ",b, " : attr ",a," : ",tostring(tex.box[b].list[a]))
    tex.sprint("\par")
  end
end
```

Later we will see that you can access properties of a node. The boxes here are so called `hlist` nodes that have a field `list` that points to the content. Because the attributes are a list themselves you can access them by indexing the node (here we do that with `[a]`). Running this snippet gives:

```
box 0 : attr 997 : 123   list 0 : attr 997 : 123
box 0 : attr 998 : 456   list 0 : attr 998 : 456
box 0 : attr 999 : nil   list 0 : attr 999 : nil
box 2 : attr 997 : 123   list 2 : attr 997 : 123
box 2 : attr 998 : nil   list 2 : attr 998 : 456
box 2 : attr 999 : 789   list 2 : attr 999 : nil
```

Because some values are not set we need to apply the `tostring` function here so that we get the word `nil`.

A special kind of box is `\vcenter`. This one also can have attributes. When one or more are set these plus the currently set attributes are bound to the resulting box. In regular \TeX these centered boxes are only permitted in math mode, but in $\text{LuaMeta}\TeX$ there is no error message and the box the height and depth are equally divided. Of course in text mode there is no math axis related offset applied.



It is possible to change or add to the attributes assigned to a box:

```
\boxattr 0 123 456
```

5.4 Lua related primitives

5.4.1 `\directlua`

In order to merge Lua code with T_EX input, a few new primitives are needed. The primitive `\directlua` is used to execute Lua code immediately. The syntax is

```
\directlua <general text>
```

The `<general text>` is expanded fully, and then fed into the Lua interpreter. After reading and expansion has been applied to the `<general text>`, the resulting token list is converted to a string as if it was displayed using `\the\toks`. On the Lua side, each `\directlua` block is treated as a separate chunk. In such a chunk you can use the `local` directive to keep your variables from interfering with those used by the macro package.

The conversion to and from a token list means that you normally can not use Lua line comments (starting with `--`) within the argument. As there typically will be only one ‘line’ the first line comment will run on until the end of the input. You will either need to use T_EX-style line comments (starting with `%`), or change the T_EX category codes locally. Another possibility is to say:

```
\begingroup  
\endlinechar=10  
\directlua ...  
\endgroup
```

Then Lua line comments can be used, since T_EX does not replace line endings with spaces. Of course such an approach depends on the macro package that you use.

The `\directlua` command is expandable. Since it passes Lua code to the Lua interpreter its expansion from the T_EX viewpoint is usually empty. However, there are some Lua functions that produce material to be read by T_EX, the so called print functions. The most simple use of these is `tex.print(<string> s)`. The characters of the string `s` will be placed on the T_EX input buffer, that is, ‘before T_EX’s eyes’ to be read by T_EX immediately. For example:

```
\count10=20  
a\directlua{tex.print(tex.count[10]+5)}b
```

expands to

```
a25b
```

Here is another example:

```
 $\pi = \directlua{tex.print(math.pi)}$
```

will result in

```
 $\pi = 3.1415926535898$ 
```



Note that the expansion of `\directlua` is a sequence of characters, not of tokens, contrary to all \TeX commands. So formally speaking its expansion is null, but it collects material in a new level on the input stack to be immediately read by \TeX after the Lua call as finished. It is a bit like $\varepsilon\text{-}\TeX$'s `\scantokens`, which now uses the same mechanism. For a description of print functions look at section 11.3.13.

Because the `<general text>` is a chunk, the normal Lua error handling is triggered if there is a problem in the included code. The Lua error messages should be clear enough, but the contextual information is often suboptimal because it can come from deep down, and \TeX has no knowledge about what you do in Lua. Often, you will only see the line number of the right brace at the end of the code.

While on the subject of errors: some of the things you can do inside Lua code can break up `LuaMetaTeX` pretty bad. If you are not careful while working with the node list interface, you may even end up with errors or even crashes from within the \TeX portion of the executable.

5.4.2 `\luaescapestring`

This primitive converts a \TeX token sequence so that it can be safely used as the contents of a Lua string: embedded backslashes, double and single quotes, and newlines and carriage returns are escaped. This is done by prepending an extra token consisting of a backslash with category code 12, and for the line endings, converting them to `n` and `r` respectively. The token sequence is fully expanded.

```
\luaescapestring <general text>
```

Most often, this command is not actually the best way to deal with the differences between \TeX and Lua. In very short bits of Lua code it is often not needed, and for longer stretches of Lua code it is easier to keep the code in a separate file and load it using Lua's `dofile`:

```
\directlua { dofile("mysetups.lua") }
```

5.4.3 `\luafunction`, `\luafunctioncall` and `\luadef`

The `\directlua` commands involves tokenization of its argument (after picking up an optional name or number specification). The tokenlist is then converted into a string and given to Lua to turn into a function that is called. The overhead is rather small but when you have millions of calls it can have some impact. For this reason there is a variant call available: `\luafunction`. This command is used as follows:

```
\directlua {  
  local t = lua.get_functions_table()  
  t[1] = function() tex.print("!") end  
  t[2] = function() tex.print("?") end  
}
```

```
\luafunction1  
\luafunction2
```



Of course the functions can also be defined in a separate file. There is no limit on the number of functions apart from normal Lua limitations. Of course there is the limitation of no arguments but that would involve parsing and thereby give no gain. The function, when called in fact gets one argument, being the index, so in the following example the number 8 gets typeset.

```
\directlua {
  local t = lua.get_functions_table()
  t[8] = function(slot) tex.print(slot) end
}
```

The `\luafunctioncall` primitive does the same but is unexpandable, for instance in an `\edef`. In addition LuaTeX provides a definer:

```
        \luadef\MyFunctionA 1
      \global\luadef\MyFunctionB 2
\protected\global\luadef\MyFunctionC 3
```

You should really use these commands with care. Some references get stored in tokens and assume that the function is available when that token expands. On the other hand, as we have tested this functionality in relative complex situations normal usage should not give problems.

It makes sense to delegate the implementation of the primitives to Lua.

5.4.4 `\luabytocode` and `\luabytodecall`

Analogue to the function callers discussed in the previous section we have byte code callers. Again the call variant is unexpandable.

```
\directlua {
  lua.bytecode[9998] = function(s)
    tex.sprint(s*token.scan_int())
  end
  lua.bytecode[5555] = function(s)
    tex.sprint(s*token.scan_dimen())
  end
}
```

This works with:

```
\luabytocode 9998 5 \luabytocode 5555 5sp
\luabytodecall9998 5 \luabytodecall5555 5sp
```

The variable `s` in the code is the number of the byte code register that can be used for diagnostic purposes. The advantage of bytecode registers over function calls is that they are stored in the format (but without upvalues).

It makes sense to delegate the implementation of the primitives to Lua.



5.5 Catcode tables

5.5.1 Catcodes

Catcode tables are a new feature that allows you to switch to a predefined catcode regime in a single statement. You can have lots of different tables, but if you need a dozen you might wonder what you're doing. This subsystem is backward compatible: if you never use the following commands, your document will not notice any difference in behaviour compared to traditional \TeX . The contents of each catcode table is independent from any other catcode table, and its contents is stored and retrieved from the format file.

5.5.2 `\catcodetable`

The primitive `\catcodetable` switches to a different catcode table. Such a table has to be previously created using one of the two primitives below, or it has to be zero. Table zero is initialized by `ini \TeX` .

```
\catcodetable <15-bit number>
```

5.5.3 `\initcatcodetable`

```
\initcatcodetable <15-bit number>
```

The primitive `\initcatcodetable` creates a new table with catcodes identical to those defined by `ini \TeX` . The new catcode table is allocated globally: it will not go away after the current group has ended. If the supplied number is identical to the currently active table, an error is raised. The initial values are:

CATCODE	CHARACTER	EQUIVALENT	CATEGORY
0	\		escape
5	^^M	return	car_ret
9	^^@	null	ignore
10	<space>	space	spacer
11	a - z		letter
11	A - Z		letter
12	everything else		other
14	%		comment
15	^^?	delete	invalid_char

5.5.4 `\savecatcodetable`

```
\savecatcodetable <15-bit number>
```

`\savecatcodetable` copies the current set of catcodes to a new table with the requested number. The definitions in this new table are all treated as if they were made in the outermost level. Again, the new table is allocated globally: it will not go away after the current group has ended. If the



supplied number is the currently active table, an error is raised.

5.6 Tokens, commands and strings

5.6.1 `\scantextokens` and `\tokenized`

The syntax of `\scantextokens` is identical to `\scantokens`. This primitive is a slightly adapted version of ε -T_EX's `\scantokens`. The differences are:

- ▶ The last (and usually only) line does not have a `\endlinechar` appended.
- ▶ `\scantextokens` never raises an EOF error, and it does not execute `\everyeof` tokens.
- ▶ There are no ‘... while end of file ...’ error tests executed. This allows the expansion to end on a different grouping level or while a conditional is still incomplete.

The implementation in LuaMetaT_EX is different in the sense that it uses the same methods as printing from Lua to T_EX does. Therefore, in addition to the two commands we also have this expandable command:

```
\tokenized ... \tokenized catcodetable <number> ...
```

The ε -T_EX command `\tracingscantokens` has been dropped in the process as that was interwoven with the old code.

5.6.2 `\toksapp`, `\tokspre`, `\etoksapp`, `\etokspre`, `\gtoksapp`, `\gtokspre`, `\xtoksapp`, `\xtokspre`

Instead of:

```
\toks0\expandafter{\the\toks0 foo}
```

you can use:

```
\etoksapp0{foo}
```

The pre variants prepend instead of append, and the e variants expand the passed general text. The g and x variants are global.

5.6.3 `\csstring`, `\beginsname` and `\lastnamedcs`

These are somewhat special. The `\csstring` primitive is like `\string` but it omits the leading escape character. This can be somewhat more efficient than stripping it afterwards.

The `\beginsname` primitive is like `\csname` but doesn't create a relaxed equivalent when there is no such name. It is equivalent to

```
\ifcsname foo\endcsname  
  \csname foo\endcsname  
\fi
```



The advantage is that it saves a lookup (don't expect much speedup) but more important is that it avoids using the `\if` test. The `\lastnamedcs` is one that should be used with care. The above example could be written as:

```
\ifcsname foo\endcsname
  \lastnamedcs
\fi
```

This is slightly more efficient than constructing the string twice (deep down in LuaTeX this also involves some utf8 juggling), but probably more relevant is that it saves a few tokens and can make code a bit more readable.

5.6.4 `\clearmarks`

This primitive complements the ϵ -TeX mark primitives and clears a mark class completely, resetting all three connected mark texts to empty. It is an immediate command (no synchronization node is used).

```
\clearmarks <16-bit number>
```

5.6.5 `\alignmark` and `\aligntab`

The primitive `\alignmark` duplicates the functionality of `#` inside alignment preambles, while `\aligntab` duplicates the functionality of `&`.

5.6.6 `\letcharcode`

This primitive can be used to assign a meaning to an active character, as in:

```
\def\foo{bar} \letcharcode123=\foo
```

This can be a bit nicer than using the uppercase tricks (using the property of `\uppercase` that it treats active characters special).

5.6.7 `\lettonothing` and `\glettonothing`

This primitive is equivalent to:

```
\protected\def\lettonothing#1{\def#1{}}
```

and although it might feel faster (only measurable with millions of calls) it's mostly there because it is easier on tracing (less clutter). An advantage over letting to an empty predefined macro is also that in tracing we keep seeing the name (relaxing would show the relax equivalent).

5.6.8 `\glet`

This primitive is similar to:



```
\protected\def\glet{\global\let}
```

but faster (only measurable with millions of calls) and probably more convenient (after all we also have `\gdef`).

5.6.9 `\defcsname`, `\edefcsname`, `\edefcsname` and `\xdefcsname`

Although we can implement these primitives easily using macros it makes sense, given the popularity of `\csname` to have these as primitives. It also saves some `\expandafter` usage and it looks a bit better in the source.

```
\def\gdefcsname foo\endcsname{oof}
```

5.6.10 `\expanded`

The `\expanded` primitive takes a token list and expands its content which can come in handy: it avoids a tricky mix of `\expandafter` and `\noexpand`. You can compare it with what happens inside the body of an `\edef`. The `\immediateassignment` and `\immediateassigned` commands are gone because we have the more powerful local control commands. They are a tad slower but this mechanism isn't used that much anyway. Inside an `\edef` you can use the `\immediate` prefix anyway, so if you really want these primitives back you can say:

```
\let\immediateassignment\immediate  
\let\immediateassigned \localcontrolled
```

5.6.11 `\ignorepars`

This primitive is like `\ignorespaces` but also skips paragraph ending commands (normally `\par` and empty lines).

5.6.12 `\futureexpand`, `\futureexpandis`, `\futureexpandisap`

These commands are used as:

```
\futureexpand\sometoken\whenfound\whennotfound
```

When there is no match and a space was gobbled a space will be put back. The `is` variant doesn't do that while the `isap` even skips `\pars`, These characters stand for 'ignorespaces' and 'ignorespacesandpars'.

5.6.13 `\aftergrouped`

There is a new experimental feature that can inject multiple tokens to after the group ends. An example demonstrate its use:

```
{
```



```

\aftergroup A \aftergroup B \aftergroup C
test 1 : }

{
  \aftergrouped{What comes next 1}
  \aftergrouped{What comes next 2}
  \aftergrouped{What comes next 3}
test 2 : }

{
  \aftergroup A \aftergrouped{What comes next 1}
  \aftergroup B \aftergrouped{What comes next 2}
  \aftergroup C \aftergrouped{What comes next 3}
test 3 : }

{
  \aftergrouped{What comes next 1} \aftergroup A
  \aftergrouped{What comes next 2} \aftergroup B
  \aftergrouped{What comes next 3} \aftergroup C
test 4 : }

```

This gives:

```

test 1 : ABC
test 2 : What comes next 1What comes next 2What comes next 3
test 3 : AWhat comes next 1BWhat comes next 2CWhat comes next 3
test 4 : What comes next 1AWhat comes next 2BWhat comes next 3C

```

5.7 Conditions

5.7.1 `\ifabsnum` and `\ifabsdim`

There are two tests that we took from pdf \TeX :

```

\ifabsnum -10 = 10
  the same number
\fi
\ifabsdim -10pt = 10pt
  the same dimension
\fi

```

This gives

```

the same number the same dimension

```



5.7.2 `\ifcmpnum`, `\ifcmpdim`, `\ifnumval`, `\ifdimval`, `\ifchknum` and `\ifchkdim`

New are the ones that compare two numbers or dimensions:

```
\ifcmpnum 5 8 less \or equal \else more \fi
\ifcmpnum 5 5 less \or equal \else more \fi
\ifcmpnum 8 5 less \or equal \else more \fi
```

less equal more

and

```
\ifcmpdim 5pt 8pt less \or equal \else more \fi
\ifcmpdim 5pt 5pt less \or equal \else more \fi
\ifcmpdim 8pt 5pt less \or equal \else more \fi
```

less equal more

There are also some number and dimension tests. All four expose the `\else` branch when there is an error, but two also report if the number is less, equal or more than zero.

```
\ifnumval -123 \or < \or = \or > \or ! \else ? \fi
\ifnumval 0 \or < \or = \or > \or ! \else ? \fi
\ifnumval 123 \or < \or = \or > \or ! \else ? \fi
\ifnumval abc \or < \or = \or > \or ! \else ? \fi
```

```
\ifdimval -123pt \or < \or = \or > \or ! \else ? \fi
\ifdimval 0pt \or < \or = \or > \or ! \else ? \fi
\ifdimval 123pt \or < \or = \or > \or ! \else ? \fi
\ifdimval abcpt \or < \or = \or > \or ! \else ? \fi
```

< = > !

< = > !

```
\ifchknum -123 \or okay \else bad \fi
\ifchknum 0 \or okay \else bad \fi
\ifchknum 123 \or okay \else bad \fi
\ifchknum abc \or okay \else bad \fi
```

```
\ifchkdim -123pt \or okay \else bad \fi
\ifchkdim 0pt \or okay \else bad \fi
\ifchkdim 123pt \or okay \else bad \fi
\ifchkdim abcpt \or okay \else bad \fi
```

okay okay okay bad

okay okay okay bad



The last checked values are available in `\lastchknum` and `\lastchkdim`. These don't obey grouping.

5.7.3 `\ifmathstyle` and `\ifmathparameter`

These two are variants on `\ifcase` where the first one operates with values in ranging from zero (display style) to seven (cramped script script style) and the second one can have three values: a parameter is zero, has a value or is unset. The `\ifmathparameter` primitive takes a proper parameter name and a valid style identifier (a primitive identifier or number). The `\ifmathstyle` primitive is equivalent to `\ifcase \mathstyle`.

5.7.4 `\ifempty`

This primitive tests for the following token (control sequence) having no content. Assuming that `\empty` is indeed empty, the following two are equivalent:

```
\ifempty\whatever  
\ifx\whatever\empty
```

There is no real performance gain here, it's more one of these extensions that lead to less clutter in tracing.

5.7.5 `\ifrelax`

This primitive complements `\ifdefined`, `\ifempty` and `\ifcurname` so that we have all reasonable tests directly available.

5.7.6 `\ifboolean`

This primitive tests for non-zero, so the next variants are similar

```
\ifcase <integer>.F.\else .T.\fi  
\unless\ifcase <integer>.T.\else .F.\fi  
\ifboolean<integer>.T.\else .F.\fi
```

5.7.7 `\iftok` and `\ifcstok`

Comparing tokens and macros can be done with `\ifx`. Two extra test are provided in LuaMetaTeX:

```
\def\ABC{abc} \def\DEF{def} \def\PQR{abc} \newtoks\XYZ \XYZ {abc}
```

```
\iftok{abc}{def}\relax (same) \else [different] \fi  
\iftok{abc}{abc}\relax [same] \else (different) \fi  
\iftok\XYZ {abc}\relax [same] \else (different) \fi
```



```

\ifcstok\ABC \DEF\relax (same) \else [different] \fi
\ifcstok\ABC \PQR\relax [same] \else (different) \fi
\ifcstok{abc}\ABC\relax [same] \else (different) \fi

```

```

[different][same][same]
[different][same][same]

```

You can check if a macro is defined as protected with `\ifprotected` while frozen macros can be tested with `\iffrozen`. A provisional `\ifusercmd` tests will check if a command is defined at the user level (and this one might evolve).

5.7.8 `\ifarguments`, `\ifparameters` and `\ifparameter`

These are part of the extended macro argument parsing features. The `\ifarguments` condition is like an `\ifcase` where the number is the picked up number of arguments. The number reflects the *last* count, so successive macro expansions will adapt the value. The `\ifparameters` counts till the first empty parameter and the `\ifparameter` (singular) takes a parameter reference (like `#2`) and again is an `\ifcase` where zero means a bad reference, one a non-empty argument and two an empty one. A typical usage is:

```

\def\foo#1#2%
  {\ifparameter#1\or one\fi
   \ifparameter#2\or two\fi}

```

No expansion of arguments takes place here but you can use a test like this:

```

\def\foo#1#2%
  {\iftok{#1}{}\else one\fi
   \iftok{#2}{}\else two\fi}

```

5.7.9 `\ifcondition`

This is a somewhat special one. When you write macros conditions need to be properly balanced in order to let \TeX 's fast branch skipping work well. This new primitive is basically a no-op flagged as a condition so that the scanner can recognize it as an if-test. However, when a real test takes place the work is done by what follows, in the next example `\something`.

```

\unexpanded\def\something#1#2%
  {\edef\tempa{#1}%
   \edef\tempb{#2}
   \ifx\tempa\tempb}

\ifcondition\something{a}{b}%
  \ifcondition\something{a}{a}%
    true 1
  \else
    false 1

```



```

    \fi
\else
  \ifcondition\something{a}{a}%
    true 2
  \else
    false 2
  \fi
\fi

```

If you are familiar with MetaPost, this is a bit like `vardef` where the macro has a return value. Here the return value is a test.

Experiments with something `\ifdef` actually worked ok but were rejected because in the end it gave no advantage so this generic one has to do. The `\ifcondition` test is basically is a no-op except when branches are skipped. However, when a test is expected, the scanner gobbles it and the next test result is used. Here is an other example:

```

\def\mytest#1%
  {\ifabsdim#1>0pt\else
    \expandafter \unless
    \fi
  \iftrue}

\ifcondition\mytest{10pt}\relax non-zero \else zero \fi
\ifcondition\mytest {0pt}\relax non-zero \else zero \fi

non-zero zero

```

The last expansion in a macro like `\mytest` has to be a condition and here we use `\unless` to negate the result.

5.7.10 `\orelse` and `\orunless`

Sometimes you have successive tests that, when laid out in the source lead to deep trees. The `\ifcase` test is an exception. Experiments with `\ifcasex` worked out fine but eventually were rejected because we have many tests so it would add a lot. As LuaMetaTeX permitted more experiments, eventually an alternative was cooked up, one that has some restrictions but is relative lightweight. It goes like this:

```

\ifnum\count0<10
  less
\orelse\ifnum\count0=10
  equal
\else
  more
\fi

```

The `\orelse` has to be followed by one of the if test commands, except `\ifcondition`, and there



can be an `\unless` in front of such a command. These restrictions make it possible to stay in the current condition (read: at the same level). If you need something more complex, using `\orelse` is probably unwise anyway. In case you wonder about performance, there is a little more checking needed when skipping branches but that can be neglected. There is some gain due to staying at the same level but that is only measurable when you runs tens of millions of complex tests and in that case it is very likely to drown in the real action. It's a convenience mechanism, in the sense that it can make your code look a bit easier to follow.

There is a nice side effect of this mechanism. When you define:

```
\def\quitcondition{\orelse\iffalse}
```

you can do this:

```
\ifnum\count0<10
  less
\orelse\ifnum\count0=10
  equal
  \quitcondition
  indeed
\else
  more
\fi
```

Of course it is only useful at the right level, so you might end up with cases like

```
\ifnum\count0<10
  less
\orelse\ifnum\count0=10
  equal
  \ifnum\count2=30
    \expandafter\quitcondition
  \fi
  indeed
\else
  more
\fi
```

The `\orunless` variant negates the next test, just like `\unless`. In some cases these commands look at the next token to see if it is an if-test so a following negation will not work (read: making that work would complicate the code and hurt efficiency too). Side note: interesting is that in ConTeXt we hardly use this kind of negation.

5.7.11 `\ifprotected`, `\frozen`, `\iffrozen` and `\ifusercmd`

These checkers deal with control sequences. You can check if a command is a protected one, that is, defined with the `\protected` prefix. A command is frozen when it has been defined with the `\frozen` prefix. Beware: only macros can be frozen. A user command is a command that is



not part of the predefined set of commands. This is an experimental command.

5.8 Boxes, rules and leaders

5.8.1 `\outputbox`

This integer parameter allows you to alter the number of the box that will be used to store the page sent to the output routine. Its default value is 255, and the acceptable range is from 0 to 65535.

```
\outputbox = 12345
```

5.8.2 `\hrule`, `\vrule`, `\nohrule` and `\novrule`

Both rule drawing commands take an optional `xoffset` and `yoffset` parameter. The displacement is virtual and not taken into account when the dimensions are calculated.

Two new primitives were introduced: `\nohrule` and `\novrule`. These can be used to reserve space. This is often more efficient than creating an empty box with fake dimensions. Of course this assumes that the backend implements them being invisible but still taking space.

5.8.3 `\vsplit`

The `\vsplit` primitive has to be followed by a specification of the required height. As alternative for the `to` keyword you can use `upto` to get a split of the given size but result has the natural dimensions then.

5.8.4 Images and reused box objects

In original \TeX image support is dealt with via specials. It's not a native feature of the engine. All that \TeX cares about is dimensions, so in practice that meant: using a box with known dimensions that wraps a special that instructs the backend to include an image. The wrapping is needed because a special itself is a `whatsit` and as such has no dimensions.

In $\text{pdf}\TeX$ a special `whatsit` for images was introduced and that one *has* dimensions. As a consequence, in several places where the engine deals with the dimensions of nodes, it now has to check the details of `whatsits`. By inheriting code from $\text{pdf}\TeX$, the $\text{Lua}\TeX$ engine also had that property. However, at some point this approach was abandoned and a more natural trick was used: images (and box resources) became a special kind of rules, and as rules already have dimensions, the code could be simplified.

When direction nodes and (formerly local) `par` nodes also became first class nodes, `whatsits` again became just that: nodes representing whatever you want, but without dimensions, and therefore they could again be ignored when dimensions mattered. And, because images were disguised as rules, as mentioned, their dimensions automatically were taken into account. This separation between front and backend cleaned up the code base already quite a bit.



In LuaMetaTeX we still have the image specific subtypes for rules, but the engine never looks at subtypes of rules. That was up to the backend. This means that image support is not present in LuaMetaTeX. When an image specification was parsed the special properties, like the filename, or additional attributes, were stored in the backend and all that LuaTeX does is registering a reference to an image's specification in the rule node. But, having no backend means nothing is stored, which in turn would make the image inclusion primitives kind of weird.

Therefore you need to realize that contrary to LuaTeX, *in LuaMetaTeX support for images and box reuse is not built in!* However, we can assume that an implementation uses rules in a similar fashion as LuaTeX does. So, you can still consider images and box reuse to be core concepts. Here we just mention the primitives that LuaTeX provides. They are not available in the engine but can of course be implemented in Lua.

COMMAND	EXPLANATION
<code>\saveboxresource</code>	save the box as an object to be included later
<code>\saveimageresource</code>	save the image as an object to be included later
<code>\useboxresource</code>	include the saved box object here (by index)
<code>\useimageresource</code>	include the saved image object here (by index)
<code>\lastsavedboxresourceindex</code>	the index of the last saved box object
<code>\lastsavedimageresourceindex</code>	the index of the last saved image object
<code>\lastsavedimageresourcepages</code>	the number of pages in the last saved image object

An implementation probably should accept the usual optional dimension parameters for `\use...resource` in the same format as for rules. With images, these dimensions are then used instead of the ones given to `\useimageresource` but the original dimensions are not overwritten, so that a `\useimageresource` without dimensions still provides the image with dimensions defined by `\saveimageresource`. These optional parameters are not implemented for `\saveboxresource`.

```
\useimageresource width 20mm height 10mm depth 5mm \lastsavedimageresourceindex
\useboxresource   width 20mm height 10mm depth 5mm \lastsavedboxresourceindex
```

Examples or optional entries are `attr` and `resources` that accept a token list, and the `type` key. When set to non-zero the `/Type` entry is omitted. A value of 1 or 3 still writes a `/BBox`, while 2 or 3 will write a `/Matrix`. But, as said: this is entirely up to the backend. Generic macro packages (like `tikz`) can use these assumed primitives so one can best provide them. It is probably, for historic reasons, the only more or less standardized image inclusion interface one can expect to work in all macro packages.

5.8.5 `\hpack`, `\vpack` and `\tpack`

These three primitives are the equivalents of `\hbox`, `\vbox` and `\vtop` but they don't trigger the packaging related callbacks. Of course one never know if content needs a treatment so using them should be done with care. Apart from accepting more keywords (and therefore options) the normal box behave the same as before. The `\vcenter` builder also works in text mode.



5.8.6 `\gleaders`

This type of leaders is anchored to the origin of the box to be shipped out. So they are like normal `\leaders` in that they align nicely, except that the alignment is based on the *largest* enclosing box instead of the *smallest*. The `g` stresses this global nature.

5.9 Languages

5.9.1 `\hyphenationmin`

This primitive can be used to set the minimal word length, so setting it to a value of 5 means that only words of 6 characters and more will be hyphenated, of course within the constraints of the `\lefthyphenmin` and `\righthyphenmin` values (as stored in the glyph node). This primitive accepts a number and stores the value with the language.

5.9.2 `\boundary`, `\noboundary`, `\protrusionboundary` and `\wordboundary`

The `\noboundary` command is used to inject a `whatsit` node but now injects a normal node with type `boundary` and subtype 0. In addition you can say:

```
x\boundary 123\relax y
```

This has the same effect but the subtype is now 1 and the value 123 is stored. The traditional ligature builder still sees this as a cancel boundary directive but at the Lua end you can implement different behaviour. The added benefit of passing this value is a side effect of the generalization. The subtypes 2 and 3 are used to control protrusion and word boundaries in hyphenation and have related primitives.

5.10 Control and debugging

5.10.1 Tracing

If `\tracingonline` is larger than 2, the node list display will also print the node number of the nodes as well as set attributes (these can be made verbose by a callback). We have only a generic `whatsit` but again a callback can be used to provide detail. So, when a box is shown in `ConTEXt` you will see quite a lot more than in other engines. Because nodes have more fields, more is shown anyway, and for nodes that have sublists (like `discretionaries`) these are also shown. All that could have been delegated to Lua but it felt wrong to not make that a core engine feature.

When bit 1 of `\tracinglevels` is set the current level is prepended to tracing lines in the log and when bit 2 is set the input level is prepended. You can set both bits and get both numbers prepended. In `ConTEXt` we default to the value 3, so you get prefixes like `3:4:` followed by a space.

When `\tracingcommands` is larger than 3 the mode switch will be not be prefixed to the `{com-`



mand} but get its own [line].

When `\tracinglevels` variable is set to 3 the group and input level are shown, a value of 1 or 2 shows only one of them (in ConTeXt we default to 3).

When `\tracinghyphenation` is set to 1 duplicate patterns are reported (in ConTeXt we default to that) and higher values will also show details about the Lua hyphenation (exception) feedback loop discussed elsewhere.

When set to 1 the `\tracingmath` variable triggers the reporting of the mode (inline or display) an mlist is processed.

Because in LuaTeX the saving and restoring of locally redefined macros and set variables is optimized a bit in order to prevent redundant stack usage, there will be less tracing visible.

Also, because we have a more extensive macro argument parser, a fast path (and less storage demands) for macros with no arguments, and flags that can be set for macros the way macros are traced can be different in details (we therefore have for instance `\meaningfull` and `\meaningless` as variants of `\meaning`).

5.10.2 `\lastnodetype`, `\lastnodesubtype`, `\currentiftype`

The ϵ -TeX command `\lastnodetype` returns the node codes as used in the engine. You can query the numbers at the Lua end if you need the actual values. The parameter `\internalcodesmode` is no longer provided as compatibility switch because LuaTeX has more cq. some different nodes and it makes no sense to be incompatible with the Lua end of the engine. The same is true for `\currentiftype`, as we have more conditionals and also use a different order. The `\lastnodesubtype` is a bonus and again reports the codes used internally. During development these might occasionally change, but eventually they will be stable.

5.11 Files

5.11.1 File syntax

LuaMetaTeX will accept a braced argument as a file name:

```
\input {plain}
\openin 0 {plain}
```

This allows for embedded spaces, without the need for double quotes. Macro expansion takes place inside the argument. Keep in mind that as side effect of delegating io to Lua the `\openin` primitive is not provided by the engine and has to be implemented by the macro package. This also means that the limit on the number of open files is not enforced by the engine.

The `\tracingfonts` primitive that has been inherited from pdfTeX has been adapted to support variants in reporting the font. The reason for this extension is that a csname not always makes sense. The zero case is the default.

VALUE	REPORTED
-------	----------

0	<code>\foo xyz</code>
---	-----------------------



```
1    \foo (bar)
2    <bar> xyz
3    <bar @ ..pt> xyz
4    <id>
5    <id: bar>
6    <id: bar @ ..pt> xyz
```

5.11.2 Writing to file

Writing to a file in \TeX has two forms: delayed and immediate. Delayed writing means that the to be written text is anchored in the node list and flushed by the backend. As all io is delegated to Lua, this also means that it has to deal with distinction. In $\text{Lua}\TeX$ the number of open files was already bumped to 127, but in $\text{LuaMeta}\TeX$ it depends on the macro package. The special meaning of channel 18 was already dropped in $\text{Lua}\TeX$ because we have `os.execute`.

5.12 Math

We will cover math extensions in its own chapter because not only the font subsystem and spacing model have been enhanced (thereby introducing many new primitives) but also because some more control has been added to existing functionality. Much of this relates to the different approaches of traditional \TeX fonts and OpenType math.

5.13 Fonts

Like math, we will cover fonts extensions in its own chapter. Here we stick to mentioning that loading fonts is different in $\text{LuaMeta}\TeX$. As in $\text{Lua}\TeX$ we have the extra primitives `\fontid` and `\setfontid`, `\noligs` and `\nokerns`, and `\nospaces`. The other new primitives in $\text{Lua}\TeX$ have been dropped.

5.14 Directions

5.14.1 Two directions

The directional model in $\text{LuaMeta}\TeX$ is a simplified version the the model used in $\text{Lua}\TeX$. In fact, not much is happening at all: we only register a change in direction.

5.14.2 How it works

The approach is that we try to make node lists balanced but also try to avoid some side effects. What happens is quite intuitive if we forget about spaces (turned into glue) but even there what happens makes sense if you look at it in detail. However that logic makes in-group switching kind of useless when no properly nested grouping is used: switching from right to left several times nested, results in spacing ending up after each other due to nested mirroring. Of course



a sane macro package will manage this for the user but here we are discussing the low level injection of directional information.

This is what happens:

```
\textdirection 1 nur {\textdirection 0 run \textdirection 1 NUR} nur
```

This becomes stepwise:

```
injected: [push 1]nur {[push 0]run [push 1]NUR} nur
balanced: [push 1]nur {[push 0]run [pop 0][push 1]NUR[pop 1]} nur[pop 0]
result   : run {RUNrun } run
```

And this:

```
\textdirection 1 nur {nur \textdirection 0 run \textdirection 1 NUR} nur
```

becomes:

```
injected: [+TRT]nur {nur [+TLT]run [+TRT]NUR} nur
balanced: [+TRT]nur {nur [+TLT]run [-TLT][+TRT]NUR[-TRT]} nur[-TRT]
result   : run {run RUNrun } run
```

Now, in the following examples watch where we put the braces:

```
\textdirection 1 nur {\{\textdirection 0 run} {\textdirection 1 NUR}} nur
```

This becomes:

```
run RUN run run
```

Compare this to:

```
\textdirection 1 nur {\{\textdirection 0 run }{\textdirection 1 NUR}} nur
```

Which renders as:

```
run RUNrun run
```

So how do we deal with the next?

```
\def\ltr{\textdirection 0\relax}
\def\rtl{\textdirection 1\relax}
```

```
run {\rtl nur {\ltr run \rtl NUR \ltr run \rtl NUR} nur}
run {\ltr run {\rtl nur \ltr RUN \rtl nur \ltr RUN} run}
```

It gets typeset as:

```
run run RUNrun RUNrun run
run run runRUN runRUN run
```

We could define the two helpers to look back, pick up a skip, remove it and inject it after the dir node. But that way we loose the subtype information that for some applications can be handy to



be kept as-is. This is why we now have a variant of `\textdirection` which injects the balanced node before the skip. Instead of the previous definition we can use:

```
\def\ltr{\linedirection 0\relax}
\def\rtl{\linedirection 1\relax}
```

and this time:

```
run {\rtl nur {\ltr run \rtl NUR \ltr run \rtl NUR} nur}
run {\ltr run {\rtl nur \ltr RUN \rtl nur \ltr RUN} run}
```

comes out as a properly spaced:

```
run run RUN run RUN run run
run run run RUN run RUN run
```

Anything more complex than this, like combination of skips and penalties, or kerns, should be handled in the input or macro package because there is no way we can predict the expected behaviour. In fact, the `\linedir` is just a convenience extra which could also have been implemented using node list parsing.

5.14.3 Normalizing lines

The original \TeX machinery was never meant to be opened up. As a consequence a constructed line can have different layouts. There can be left- and/or right skips and hanging indentation or parshape can result in a shift and adapted width. In $\text{Lua}\TeX$ glue got subtypes so we can recognize the left-, right and parfill skips, but still there is no hundred percent certainty about the shape.

In $\text{LuaMeta}\TeX$ lines can be normalized. This is optional because we want to preserve the original (for comparison) and is controlled by `\normalizelinemode`. That variable actually drives some more. An earlier version provided a few more granular options (for instance: does a leftskip comes before or after a left hanging indentation) but in the end that was dropped. Because this normalization only is seen at the Lua end there is no need to go into much detail here.

At this moment a line has this pattern: left parfill, left hang, left skip, indentation, content, right hang, right skip, right parfill. Of course the indentation and fill skips are not present in every line.

Control over normalization happens via the mentioned mode variable and here is what the engine provides right now. We use a bitmap:

VALUE	REPORTED
0x0001	normalize line as described above
0x0002	use a skip for parindent instead of a box
0x0004	swap hangindent in l2r mode
0x0008	swap parshape in l2r mode
0x0010	put breaks after dir in l2r mode



0x0020 remove margin kerns (pdf \TeX left-over)
0x0040 if needed clip width and use correction kern

Setting the bit enables the related normalization. More features might be added in future releases.

5.14.4 Orientations

As mentioned, the difference with Lua \TeX is that we only have numeric directions and that there are only two: left-to-right (0) and right-to-left (1). The direction of a box is set with `direction`. In addition to that boxes can now have an `orientation` keyword followed by optional `xoffset` and/or `yoffset` keywords. The offsets don't have consequences for the dimensions. The alternatives `xmove` and `ymove` on the contrary are reflected in the dimensions. Just play with them. The offsets and moves only are accepted when there is also an orientation, so no time is wasted on testing for these rarely used keywords. There are related primitives `\box...` that set these properties.

As these are experimental it will not be explained here (yet). They are covered in the descriptions of the development of LuaMeta \TeX : articles and/or documents in the Con \TeX t distribution. For now it is enough to know that the orientation can be up, down, left or right (rotated) and that it has some anchoring variants. Combined with the offsets this permits macro writers to provide solutions for top-down and bottom-up writing directions, something that is rather macro package specific and used for scripts that need manipulations anyway. The 'old' vertical directions were never okay and therefore not used.

There are a couple of properties in boxes that you can set and query but that only really take effect when the backend supports them. When usage on Con \TeX t shows that is't okay, they will become official, so we just mention them: `\boxdirection`, `\boxattr`, `\boxorientation`, `\boxxoffset`, `\boxyoffset`, `\boxxmove`, `\boxymove` and `\boxtotal`.

This is still somewhat experimental and will be documented in more detail when I've used it more in Con \TeX t and the specification is frozen. This might take some time (and user input).

5.15 Keywords

Some primitives accept one or more keywords and LuaMeta \TeX adds some more. In order to deal with this efficiently the keyword scanner has been optimized, where even the context was taken into account. As a result the scanner was quite a bit faster. This kind of optimization was a graduate process the eventually ended up in what we have now. In traditional \TeX (and also Lua \TeX) the order of keywords is sometimes mixed and sometimes prescribed. In most cases only one occurrence is permitted. So, for instance, this is valid in Lua \TeX :

```
\hbox attr 123 456 attr 123 456 spread 10cm { }  
\hrule width 10cm depth 3mm  
\hskip 3pt plus 2pt minus 1pt
```

The `attr` comes before the `spread`, rules can have multiple mixed dimension specifiers, and in glue the optional `minus` part always comes last. The last two commands are famous for look



ahead side effects which is why macro packages will end them with something not keyword, like `\relax`, when needed.

In LuaMetaTeX the following is okay. Watch the few more keywords in box and rule specifications.

```
\hbox reverse to 10cm attr 123 456 orientation 4 xoffset 10pt spread 10cm { }
\hrule xoffset 10pt width 10cm depth 3mm
\hskip 3pt minus 1pt plus 2pt
```

Here the order is not prescribed and, as demonstrated with the box specifier, for instance dimensions (specified by `to` or `spread` can be overloaded by later settings. In case you wonder if that breaks compatibility: in some way it does but bad or sloppy keyword usage breaks a run anyway. For instance `minuscule` results in `minus` with no dimension being seen. So, in the end the user should not notice it and when a user does, the macro package already had an issue that had to be fixed.

5.16 Expressions and `\numericsscale`

The `*expr` parsers now accept `:` as operator for integer division (the `/` operators does rounding. This can be used for division compatible with `\divide`. I'm still wondering if adding a couple of bit operators makes sense (for integers).

The `\numericsscale` parser is kind of special (and might evolve). For now it converts a following number in a scale value as often used in TeX, where 1000 means scaling by 1.0. The trick is in the presence of a digit (or comma): 1.234 becomes 1234 but 1234 stays 1234 and from this you can deduce that 12.34 becomes 123400. Internally TeX calculates with integers, but this permits the macro package to provide an efficient mix.

5.17 Macro arguments

Again this is experimental and (used and) discussed in document that come with the ConTeXt distribution. When defining a macro you can do this:

```
\def\foo(#1)#2{...}
```

Here the first argument between parentheses is mandatory. But the magic prefix `\tolerant` makes that limitation go away:

```
\tolerant\def\foo(#1)#2{...}
```

A variant is this:

```
\tolerant\def\foo(#1)#*(#2){...}
```

Here we have two optional arguments, possibly be separated by spaces. There are more parsing options:



+	keep the braces
-	discard and don't count the argument
/	remove leading and trailing spaces and pars
=	braces are mandate
_	braces are mandate and kept
^	keep leading spaces

1-9	an argument
0	discard but count the argument

*	ignore spaces
.	ignore pars and spaces
,	push back space when no match

:	pick up scanning here
;	quit scanning

For the moment we leave it to your fantasy what these options do. Most probably only make sense when you write a bit more complex macros. Just try to imagine what this does:

```
\permanent\tolerant\global\protected\def\foo(#1)*##;[#2]#:#3{...}
```

Of course complex combinations can be confusing because after all $\text{T}_{\text{E}}\text{X}$ is parsing for (multi-token) delimiters and will happily gobble the whole file if you are not careful. You can quit scanning if you want:

```
\macro 123\ignorearguments
```

which of course only makes sense when used in a nested call where an already picked up arguments is processed further. A not (yet) discussed feature of the parser is that it will happily skip tokens that have the (probably seldom used) ignored characters property.

When you use tracing or see error messages arguments defined using for instance `#=` will have their usual number in the macro body, so you need to keep track of the numbers.

All this is rather easy on the engine and although it might have a little impact on performance this has been compensated by some more efficiency in the macro parser and engine in general and of course you can gain back some by using these features.

5.18 Overload protection

There is an experimental overload protection mechanism that we will test for a while before declaring it stable. The reason for that is that we need to adapt the $\text{ConT}_{\text{E}}\text{Xt}$ code base in order to test its usefulness. Protection is achieved via prefixes. Depending on the value of the `\overloadmode` variable warnings or errors will be triggered. Examples of usage can be found in some documents that come with $\text{ConT}_{\text{E}}\text{Xt}$, so here we just stick to the basics.

```
\mutable \def\foo{...}
\immutable\def\foo{...}
\permanent\def\foo{...}
```



```
\frozen   \def\foo{...}
\aliased  \def\foo{...}
```

A `\mutable` macro can always be changed contrary to an `\immutable` one. For instance a macro that acts as a variable is normally `\mutable`, while a constant can best be `\immutable`. It makes sense to define a public core macro as `\permanent`. Primitives start out as `\permanent` ones but with a primitive property instead.

```
\let\relaxone  \relax 1: \meaningfull\relaxone
\aliased \let\relaxtwo \relax 2: \meaningfull\relaxtwo
\permanent\let\relaxthree\relax 3: \meaningfull\relaxthree
```

The `\meaningfull` primitive is like `\meaning` but reports the properties too. The `\meaningless` companion reports the body of a macro. Anyway, this typesets:

```
1: \relax
2: primitive \relax
3: permanent \relax
```

So, the `\aliased` prefix copies the properties. Keep in mind that a macro package can redefine primitives, but `\relax` is an unlikely candidate.

There is an extra prefix `\noaligned` that flags a macro as being valid for `\noalign` compatible usage (which means that the body must contain that one). The idea is that we then can do this:

```
\permanent\protected\noaligned\def\foo{\noalign{...}} % \foo is unexpandable
```

that is: we can have protected macros that don't trigger an error in the parser where there is a look ahead for `\noalign` which is why normally protection doesn't work well. So: we have macro flagged as permanent (overload protection), being protected (that is, not expandable by default) and a valid equivalent of the `\noalign` primitive. Of course we can also apply the `\global` and `\tolerant` prefixes here. The complete repertoire of extra prefixes is:

<code>frozen</code>	a macro that has to be redefined in a managed way
<code>permanent</code>	a macro that had better not be redefined
<code>primitive</code>	a primitive that normally will not be adapted
<code>immutable</code>	a macro or quantity that cannot be changed, it is a constant
<code>mutable</code>	a macro that can be changed no matter how well protected it is

<code>instance</code>	a macro marked as (for instance) be generated by an interface
-----------------------	---

<code>noaligned</code>	the macro becomes acceptable as <code>\noalign</code> alias
------------------------	---

<code>overloaded</code>	when permitted the flags will be adapted
<code>enforced</code>	all is permitted (but only in zero mode or ini mode)
<code>aliased</code>	the macro gets the same flags as the original

The not yet discussed `\instance` is just a flag with no special meaning which can be used as classifier. The `\frozen` also protects against overload which brings amount of blockers to four. To what extent the engine will complain when a property is changed in a way that violates the flags depends on the parameter `\overloadmode`. When this parameter is set to zero no checking



takes place. More interesting are values larger than zero. If that is the case, when a control sequence is flagged as mutable, it is always permitted to change. When it is set to immutable one can never change it. The other flags determine the kind of checking done. Currently the following overload values are used:

	immutable	permanent	primitive	frozen	instance
1 warning	*	*	*		
2 error	*	*	*		
3 warning	*	*	*	*	
4 error	*	*	*	*	
5 warning	*	*	*	*	*
6 error	*	*	*	*	*

The even values (except zero) will abort the run. A value of 255 will freeze this parameter. At level five and above the `\instance` flag is also checked but no drastic action takes place. We use this to signal to the user that a specific instance is redefined (of course the definition macros can check for that too).

The `\overloaded` prefix can be used to overload a frozen macro. The `\enforced` is more powerful and forces an overload but that prefix is only effective in ini mode or when it's embedded in the body of a macro or token list at ini time unless of course at runtime the mode is zero.

So far for a short explanation. More details can be found in the `ConTeXt` documentation where we can discuss it in a more relevant perspective. It must be noted that this feature only makes sense a controlled situation, that is: user modules or macros of unpredictable origin will probably suffer from warnings and errors when de mode is set to non zero. In `ConTeXt` we're okay unless of course users redefine instances but there a warning or error is kind of welcome.

5.19 Constants with `\integerdef` and `\dimendef`

It is rather common to store constant values in a register or character definition.

```
\newcount\MyConstantA \MyConstantA 123
\newdimen\MyConstantB \MyConstantB 123pt
\chardef \MyConstantC \MyConstantC 123
```

But in `LuaMetaTeX` we also can do this:

```
\integerdef\MyConstantC 456
\dimendef \MyConstantD 456pt
```

These two are stored as efficient as a register but don't occupy a register slot. They can be set as above, need `\the` for serializations and are seen as valid number or dimension when needed.

Experiments with constant strings made the engine source more complex than I wanted so that features was rejected. Of course we can use the prefixes mentioned in a previous section.



5.20 Serialization with `\todimension`, `\toscaled` and `\tointeger`

These three serializers take a verbose or symbolic quantity:

```
\todimension 10pt    \todimension \scratchdimen    % with unit
\toscaled    10pt    \toscaled    \scratchdimen    % without unit
\tointeger   10      \tointeger   \scratchcounter
```

This is particularly handy in cases where you don't know what you deal with, for instance when a value is stored in a macro. Using `\the` could fail there while:

```
\the\dimexpr10pt\relax
```

is often overkill and gives more noise in a trace.

5.21 Nodes

The ϵ -TeX primitive `\lastnodetype` is not honest in reporting the internal numbers as it uses its own values. But you can set `\internalcodesmode` to a non-zero value to get the real id's instead. In addition there is `\lastnodesubtype`.

Another last one is `\lastnamedcs` which holds the last match but this one should be used with care because one never knows if in the meantime something else 'last' has been seen.





6 Fonts

6.1 Introduction

Only traditional font support is built in, anything more needs to be implemented in Lua. This conforms to the Lua \TeX philosophy. When you pass a font to the frontend only the dimensions matter, as these are used in typesetting, and optionally ligatures and kerns when you rely on the built-in font handler. For math some extra data is needed, like information about extensibles and next in size glyphs. You can of course put more information in your Lua tables because when such a table is passed to \TeX only that what is needed is filtered from it.

Because there is no built-in backend, virtual font information is not used. If you want to be compatible you'd better make sure that your tables are okay, and in that case you can best consult the Lua \TeX manual. For instance, parameters like `extend` are backend related and the standard Lua \TeX backend sets the standard here.

6.2 Defining fonts

All \TeX fonts are represented to Lua code as tables, and internally as C structures. All keys in the table below are saved in the internal font structure if they are present in the table passed to `font.define`. When the callback is set, which is needed for `\font` to work, its function gets the name and size passed, and it has to return a valid font identifier (a positive number).

For the engine to work well, the following information has to be present at the font level:

KEY	VALUE TYPE	DESCRIPTION
<code>name</code>	string	metric (file) name
<code>characters</code>	table	the defined glyphs of this font
<code>designsize</code>	number	expected size (default: $655360 == 10\text{pt}$)
<code>fonts</code>	table	locally used fonts
<code>hyphenchar</code>	number	default: \TeX 's <code>\hyphenchar</code>
<code>parameters</code>	hash	default: 7 parameters, all zero
<code>size</code>	number	the required scaling (by default the same as <code>designsize</code>)
<code>skewchar</code>	number	default: \TeX 's <code>\skewchar</code>
<code>stretch</code>	number	the 'stretch'
<code>shrink</code>	number	the 'shrink'
<code>step</code>	number	the 'step'
<code>nomath</code>	boolean	this key allows a minor speedup for text fonts; if it is present and true, then Lua \TeX will not check the character entries for math-specific keys
<code>oldmath</code>	boolean	this key flags a font as representing an old school \TeX math font and disables the OpenType code path

The `parameters` is a hash with mixed key types. There are seven possible string keys, as well as a number of integer indices (these start from 8 up). The seven strings are actually used instead of the bottom seven indices, because that gives a nicer user interface.



The names and their internal remapping are:

NAME	REMAPPING
slant	1
space	2
space_stretch	3
space_shrink	4
x_height	5
quad	6
extra_space	7

The characters table is a Lua hash table where the keys are integers. When a character in the input is turned into a glyph node, it gets a character code that normally refers to an entry in that table. For proper paragraph building and math rendering the following fields can be present in an entry in the characters table. You can of course add all kind of extra fields. The engine only uses those that it needs for typesetting a paragraph or formula. The subtables that define ligatures and kerns are also hashes with integer keys, and these indices should point to entries in the main characters table.

Providing ligatures and kerns this way permits T_EX to construct ligatures and add inter-character kerning. However, normally you will use an OpenType font in combination with Lua code that does this. In ConT_EXt we have base mode that uses the engine, and node mode that uses Lua. A monospaced font normally has no ligatures and kerns and is normally not processed at all.

KEY	TYPE	DESCRIPTION
width	number	width in sp (default 0)
height	number	height in sp (default 0)
depth	number	depth in sp (default 0)
italic	number	italic correction in sp (default 0)
top_accent	number	top accent alignment place in sp (default zero)
bot_accent	number	bottom accent alignment place, in sp (default zero)
left_protruding	number	left protruding factor (<code>\lpcode</code>)
right_protruding	number	right protruding factor (<code>\rpcode</code>)
expansion_factor	number	expansion factor (<code>\efcode</code>)
next	number	'next larger' character index
extensible	table	constituent parts of an extensible recipe
vert_variants	table	constituent parts of a vertical variant set
horiz_variants	table	constituent parts of a horizontal variant set
kerns	table	kerning information
ligatures	table	ligaturing information
mathkern	table	math cut-in specifications

For example, here is the character 'f' (decimal 102) in the font cmr10 at 10pt. The numbers that represent dimensions are in scaled points.

```
[102] = {
  ["width"] = 200250,
```



```

["height"] = 455111,
["depth"] = 0,
["italic"] = 50973,
["kerns"] = {
    [63] = 50973,
    [93] = 50973,
    [39] = 50973,
    [33] = 50973,
    [41] = 50973
},
["ligatures"] = {
    [102] = { ["char"] = 11, ["type"] = 0 },
    [108] = { ["char"] = 13, ["type"] = 0 },
    [105] = { ["char"] = 12, ["type"] = 0 }
}
}

```

Two very special string indexes can be used also: `left_boundary` is a virtual character whose ligatures and kerns are used to handle word boundary processing. `right_boundary` is similar but not actually used for anything (yet).

The values of `top_accent`, `bot_accent` and `mathkern` are used only for math accent and superscript placement, see page 101 in this manual for details. The values of `left_protruding` and `right_protruding` are used only when `\protrudechars` is non-zero. Whether or not `expansion_factor` is used depends on the font's global expansion settings, as well as on the value of `\adjustspacing`.

A math character can have a `next` field that points to a next larger shape. However, the presence of `extensible` will overrule `next`, if that is also present. The `extensible` field in turn can be overruled by `vert_variants`, the OpenType version. The `extensible` table is very simple:

KEY	TYPE	DESCRIPTION
<code>top</code>	number	top character index
<code>mid</code>	number	middle character index
<code>bot</code>	number	bottom character index
<code>rep</code>	number	repeatable character index

The `horiz_variants` and `vert_variants` are arrays of components. Each of those components is itself a hash of up to five keys:

KEY	TYPE	EXPLANATION
<code>glyph</code>	number	The character index. Note that this is an encoding number, not a name.
<code>extender</code>	number	One (1) if this part is repeatable, zero (0) otherwise.
<code>start</code>	number	The maximum overlap at the starting side (in scaled points).
<code>end</code>	number	The maximum overlap at the ending side (in scaled points).
<code>advance</code>	number	The total advance width of this item. It can be zero or missing, then the natural size of the glyph for character component is used.



The kerns table is a hash indexed by character index (and ‘character index’ is defined as either a non-negative integer or the string value `right_boundary`), with the values of the kerning to be applied, in scaled points.

The ligatures table is a hash indexed by character index (and ‘character index’ is defined as either a non-negative integer or the string value `right_boundary`), with the values being yet another small hash, with two fields:

KEY	TYPE	DESCRIPTION
<code>type</code>	number	the type of this ligature command, default 0
<code>char</code>	number	the character index of the resultant ligature

The `char` field in a ligature is required. The `type` field inside a ligature is the numerical or string value of one of the eight possible ligature types supported by T_EX. When T_EX inserts a new ligature, it puts the new glyph in the middle of the left and right glyphs. The original left and right glyphs can optionally be retained, and when at least one of them is kept, it is also possible to move the new ‘insertion point’ forward one or two places. The glyph that ends up to the right of the insertion point will become the next ‘left’.

TEXTUAL (KNUTH)	NUMBER	STRING	RESULT
<code>l + r =: n</code>	0	<code>=:</code>	<code> n</code>
<code>l + r =: n</code>	1	<code>=: </code>	<code> nr</code>
<code>l + r =: n</code>	2	<code> =:</code>	<code> ln</code>
<code>l + r =: n</code>	3	<code> =: </code>	<code> lnr</code>
<code>l + r =: > n</code>	5	<code>=: ></code>	<code>n r</code>
<code>l + r =:> n</code>	6	<code> =:></code>	<code>l n</code>
<code>l + r =: > n</code>	7	<code> =: ></code>	<code>l nr</code>
<code>l + r =: >> n</code>	11	<code> =: >></code>	<code>ln r</code>

The default value is 0, and can be left out. That signifies a ‘normal’ ligature where the ligature replaces both original glyphs. In this table the `|` indicates the final insertion point.

6.3 Virtual fonts

Virtual fonts have been introduced to overcome limitations of good old T_EX. They were mostly used for providing a direct mapping from for instance accented characters onto a glyph. The backend was responsible for turning a reference to a character slot into a real glyph, possibly constructed from other glyphs. In our case there is no backend so there is also no need to pass this information through T_EX. But it can of course be part of the font information and because it is a kind of standard, we describe it here.

A character is virtual when it has a `commands` array as part of the data. A virtual character can itself point to virtual characters but be careful with nesting as you can create loops and overflow the stack (which often indicates an error anyway).

At the font level there can be a an (indexed) `fonts` table. The values are one- or two-key hashes themselves, each entry indicating one of the base fonts in a virtual font. In case your font is referring to itself in for instance a virtual font, you can use the `slot` command with a zero font



reference, which indicates that the font itself is used. So, a table looks like this:

```

fonts = {
  { name = "ptmr8a", size = 655360 },
  { name = "psyr", size = 600000 },
  { id = 38 }
}

```

The first referenced font (at index 1) in this virtual font is ptmr8a loaded at 10pt, and the second is psyr loaded at a little over 9pt. The third one is a previously defined font that is known to LuaTeX as font id 38. The array index numbers are used by the character command definitions that are part of each character.

The commands array is a hash where each item is another small array, with the first entry representing a command and the extra items being the parameters to that command. The frontend is only interested in the dimensions, ligatures and kerns of a font, which is the reason why the TeX engine didn't have to be extended when virtual fonts showed up: dealing with it is up to the driver that comes after the backend. In pdfTeX and LuaTeX that driver is integrated so there the backend also deals with virtual fonts. The first block in the next table is what the standard mentions. The special command is indeed special because it is an extension container. The mentioned engines only support pseudo standards where the content starts with pdf:. The last block is LuaTeX specific and will not be found in native fonts. These entries can be used in virtual fonts that are constructed in Lua.

But ... in LuaMetaTeX there is no backend built in but we might assume that the one provided deals with these entries. However, a provided backend can provide more and that is indeed what happens in ConTeXt. There, because we no longer have compacting (of passed tables) and unpacking (when embedding) of these tables going on we stay in the Lua domain. None of the virtual specification is ever seen in the engine.

COMMAND	ARGUMENTS	TYPE	DESCRIPTION
font	1	number	select a new font from the local fonts table
char	1	number	typeset this character number from the current font, and move right by the character's width
push	0		save current position
pop	0		pop position
rule	2	2 numbers	output a rule $ht * wd$, and move right.
down	1	number	move down on the page
right	1	number	move right on the page
special	1	string	output a \special command
nop	0		do nothing
slot	2	2 numbers	a shortcut for the combination of a font and char command
node	1	node	output this node (list), and move right by the width of this list
pdf	2	2 strings	output a pdf literal, the first string is one of origin, page, text, font, direct or raw; if you have one string only origin is assumed



lua	1	string, function	execute a Lua script when the glyph is embedded; in case of a function it gets the font id and character code passed
image	1	image	output an image (the argument can be either an <image> variable or an image_spec table)
comment	any	any	the arguments of this command are ignored

When a font id is set to 0 then it will be replaced by the currently assigned font id. This prevents the need for hackery with future id's.

The pdf option also accepts a mode keyword in which case the third argument sets the mode. That option will change the mode in an efficient way (passing an empty string would result in an extra empty lines in the pdf file. This option only makes sense for virtual fonts. The font mode only makes sense in virtual fonts. Modes are somewhat fuzzy and partially inherited from pdf_TE_X.

MODE	DESCRIPTION
origin	enter page mode and set the position
page	enter page mode
text	enter text mode
font	enter font mode (kind of text mode, only in virtual fonts)
always	finish the current string and force a transform if needed
raw	finish the current string

You always need to check what pdf code is generated because there can be all kind of interferences with optimization in the backend and fonts are complicated anyway. Here is a rather elaborate glyph commands example using such keys:

```
...
commands = {
  { "push" }, -- remember where we are
  { "right", 5000 }, -- move right about 0.08pt
  { "font", 3 }, -- select the fonts[3] entry
  { "char", 97 }, -- place character 97 (ASCII 'a')
  -- { "slot", 2, 97 }, -- an alternative for the previous two
  { "pop" }, -- go all the way back
  { "down", -200000 }, -- move upwards by about 3pt
  { "special", "pdf: 1 0 0 rg" } -- switch to red color
  -- { "pdf", "origin", "1 0 0 rg" } -- switch to red color (alternative)
  { "rule", 500000, 20000 } -- draw a bar
  { "special", "pdf: 0 g" } -- back to black
  -- { "pdf", "origin", "0 g" } -- back to black (alternative)
}
...
```

The default value for font is always 1 at the start of the commands array. Therefore, if the virtual font is essentially only a re-encoding, then you do usually not have created an explicit 'font' command in the array.



Rules inside of commands arrays are built up using only two dimensions: they do not have depth. For correct vertical placement, an extra down command may be needed.

Regardless of the amount of movement you create within the commands, the output pointer will always move by exactly the width that was given in the width key of the character hash. Any movements that take place inside the commands array are ignored on the upper level.

The special can have a pdf:, pdf:origin:, pdf:page:, pdf:direct: or pdf:raw: prefix. When you have to concatenate strings using the pdf command might be more efficient.

6.4 Additional T_EX commands

6.4.1 Font syntax

LuaT_EX will accept a braced argument as a font name:

```
\font\myfont = {cmr10}
```

This allows for embedded spaces, without the need for double quotes. Macro expansion takes place inside the argument.

6.4.2 \fontid and \setfontid

```
\fontid\font
```

This primitive expands into a number. The currently used font id is 14. Here are some more:³

STYLE	COMMAND	FONT ID
normal	\tf	14
bold	\bf	18
italic	\it	23
bold italic	\bi	24

These numbers depend on the macro package used because each one has its own way of dealing with fonts. They can also differ per run, as they can depend on the order of loading fonts. For instance, when in ConT_EXt virtual math Unicode fonts are used, we can easily get over a hundred ids in use. Not all ids have to be bound to a real font, after all it's just a number.

The primitive \setfontid can be used to enable a font with the given id, which of course needs to be a valid one.

6.4.3 \glyphoptions

In LuaT_EX the \noligs and \nokerns primitives suppress these features but in LuaMetaT_EX these primitives are gone. They are replaced by a more generic control primitive \glyphoptions. This

³ Contrary to LuaT_EX this is now a number so you need to use \number or \the. The same is true for some other numbers and dimensions that for some reason ended up in the serializer that produced a sequence of tokens.



numerical parameter is a bitset with the following fields:

VALUE	EFFECT
0x01	prevent left ligature
0x02	prevent right ligature
0x04	block left kern
0x08	block right kern
0x10	don't apply expansion
0x20	don't apply protrusion
0x40	apply xoffset to width
0x80	apply yoffset to height and depth

The effects speak for themselves. They provide detailed control over individual glyph, this because the current value of this option is stored with glyphs.

6.4.4 `\glyphxscale`, `\glyphyscale` and `\scaledfontdimen`

The two scale parameters control the current scaling. They are traditional \TeX integer parameters that operate independent of each other. The scaling is reflected in the dimensions of glyphs as well as in the related font dimensions, which means that units like `ex` and `em` work as expected. If you query a font dimensions with `\fontdimen` you get the raw value but with `\scaledfontdimen` you get the useable value.

6.4.5 `\glyphxoffset`, `\glyphyoffset`

These two parameters control the horizontal and vertical shift of glyphs with, when applied to a stretch of them, the horizontal offset probably being the least useful.

6.4.6 `\glyph`

This command is a variation in `\char` that takes keywords:

KEYWORD	EFFECT	type
<code>xoffset</code>	(virtual) horizontal shift	dimension
<code>yoffset</code>	(virtual) vertical shift	dimension
<code>xscale</code>	horizontal scaling	integer
<code>yscale</code>	vertical scaling	integer
<code>options</code>	glyph options	bitset
<code>font</code>	font	identifier
<code>id</code>	font	integer

The values default to the currently set values. Here is a $\text{Con}\TeX$ t example:

```
\ruledhbox{
  \ruledhbox{\glyph yoffset 1ex options 0 123}
  \ruledhbox{\glyph xoffset .5em yoffset 1ex options "C0 125}
```



```
\ruledhbox{baseline\glyphyoffset 1ex \glyphxscale 800 \glyphyscale\glyphx-
cale raised}
}
```

Visualized:

```
{ } baseline raised
```

6.4.7 \nospaces

This new primitive can be used to overrule the usual `\spaceskip` related heuristics when a space character is seen in a text flow. The value 1 triggers no injection while 2 results in injection of a zero skip. In figure 6.1 we see the results for four characters separated by a space.

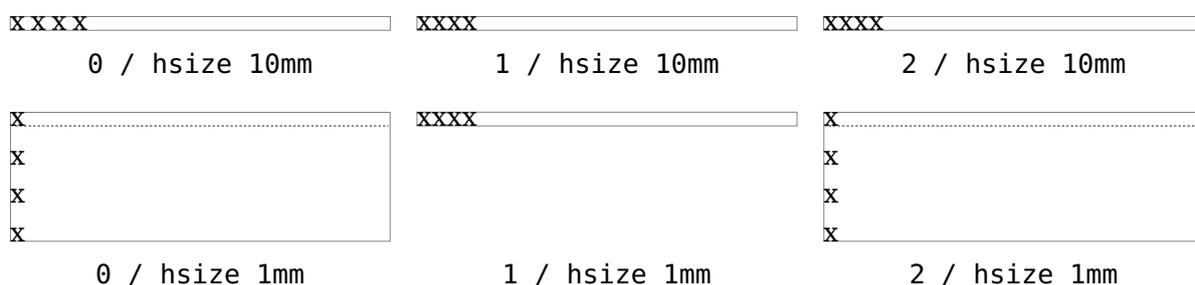


Figure 6.1 The `\nospaces` options.

6.4.8 \protrusionboundary

The protrusion detection mechanism is enhanced a bit to enable a bit more complex situations. When protrusion characters are identified some nodes are skipped:

- ▶ zero glue
- ▶ penalties
- ▶ empty discretionaries
- ▶ normal zero kerns
- ▶ rules with zero dimensions
- ▶ math nodes with a surround of zero
- ▶ dir nodes
- ▶ empty horizontal lists
- ▶ local par nodes
- ▶ inserts, marks and adjusts
- ▶ boundaries
- ▶ whatsits

Because this can not be enough, you can also use a protrusion boundary node to make the next node being ignored. When the value is 1 or 3, the next node will be ignored in the test when locating a left boundary condition. When the value is 2 or 3, the previous node will be ignored when locating a right boundary condition (the search goes from right to left). This permits protrusion combined with for instance content moved into the margin:

```
\protrusionboundary1\llap{!\quad}«Who needs protrusion?»
```



6.5 The Lua font library

6.5.1 Introduction

The Lua font library is reduced to a few commands. Contrary to Lua \TeX there is no loading of `tfm` or `vf` files. The explanation of the following commands is in the Lua \TeX manual.

FUNCTION	DESCRIPTION
<code>current</code>	returns the id of the currently active font
<code>max</code>	returns the last assigned font identifier
<code>setfont</code>	enables a font <code>setfont</code> (sets the current font id)
<code>addcharacters</code>	adds characters to a font
<code>define</code>	defined a font
<code>id</code>	returns the id that relates to a command name

For practical reasons the management of font identifiers is still done by \TeX but it can become an experiment to delegate that to Lua as well.

6.5.2 Defining a font with `define`, `addcharacters` and `setfont`

Normally you will use a callback to define a font but there's also a Lua function that does the job.

```
id = font.define(<table> f)
```

Within reasonable bounds you can extend a font after it has been defined. Because some properties are best left unchanged this is limited to adding characters.

```
font.addcharacters(<number n>, <table> f)
```

The table passed can have the fields `characters` which is a (sub)table like the one used in `define`, and for virtual fonts a `fonts` table can be added. The characters defined in the `characters` table are added (when not yet present) or replace an existing entry. Keep in mind that replacing can have side effects because a character already can have been used. Instead of posing restrictions we expect the user to be careful. The `setfont` helper is a more drastic replacer and only works when a font has not been used yet.

6.5.3 Font ids: `id`, `max` and `current`

```
<number> i = font.id(<string> csname)
```

This returns the font id associated with `csname`, or `-1` if `csname` is not defined.

```
<number> i = font.max()
```

This is the largest used index so far. The currently active font id can be queried or set with:



```
<number> i = font.current()  
font.current(<number> i)
```

6.5.4 Glyph data: `\glyphdata`, `\glyphscript`, `\glyphstate`

These primitives can be used to set an additional glyph properties. Of course it's very macro package dependant what is done with that. It started with just the first one as experiment, simply because we had some room left in the glyph data structure. It's basically an single attribute. Then, when we got rid of the ligature pointer we could either drop it or use that extra field for some more, and because ConT_EXt already used the data field, that is what happened. The script and state fields are shorts, that is, they run from zero to 0xFFFF where we assume that zero means 'unset'. Although they can be used for whatever purpose their use in ConT_EXt is fixed.





7 Languages, characters, fonts and glyphs

7.1 Introduction

LuaTeX's internal handling of the characters and glyphs that eventually become typeset is quite different from the way TeX82 handles those same objects. The easiest way to explain the difference is to focus on unrestricted horizontal mode (i.e. paragraphs) and hyphenation first. Later on, it will be easy to deal with the differences that occur in horizontal and math modes.

In TeX82, the characters you type are converted into char node records when they are encountered by the main control loop. TeX attaches and processes the font information while creating those records, so that the resulting 'horizontal list' contains the final forms of ligatures and implicit kerning. This packaging is needed because we may want to get the effective width of for instance a horizontal box.

When it becomes necessary to hyphenate words in a paragraph, TeX converts (one word at time) the char node records into a string by replacing ligatures with their components and ignoring the kerning. Then it runs the hyphenation algorithm on this string, and converts the hyphenated result back into a 'horizontal list' that is consecutively spliced back into the paragraph stream. Keep in mind that the paragraph may contain unboxed horizontal material, which then already contains ligatures and kerns and the words therein are part of the hyphenation process.

Those char node records are somewhat misnamed, as they are glyph positions in specific fonts, and therefore not really 'characters' in the linguistic sense. There is no language information inside the char node records at all. Instead, language information is passed along using language whatsit nodes inside the horizontal list.

In LuaTeX, the situation is quite different. The characters you type are always converted into glyph node records with a special subtype to identify them as being intended as linguistic characters. LuaTeX stores the needed language information in those records, but does not do any font-related processing at the time of node creation. It only stores the index of the current font and a reference to a character in that font.

When it becomes necessary to typeset a paragraph, LuaTeX first inserts all hyphenation points right into the whole node list. Next, it processes all the font information in the whole list (creating ligatures and adjusting kerning), and finally it adjusts all the subtype identifiers so that the records are 'glyph nodes' from now on.

7.2 Characters, glyphs and discretionaries

TeX82 (including pdfTeX) differentiates between char nodes and lig nodes. The former are simple items that contained nothing but a 'character' and a 'font' field, and they lived in the same memory as tokens did. The latter also contained a list of components, and a subtype indicating whether this ligature was the result of a word boundary, and it was stored in the same place as other nodes like boxes and kerns and glues. In LuaMetaTeX we no longer keep the list of components with the glyph node.



In Lua \TeX , these two types are merged into one, somewhat larger structure called a glyph node. Besides having the old character, font, and component fields there are a few more, like ‘attr’ that we will see in section 9.2.12, these nodes also contain a subtype, that codes four main types and two additional ghost types. For ligatures, multiple bits can be set at the same time (in case of a single-glyph word).

- ▶ character, for characters to be hyphenated: the lowest bit (bit 0) is set to 1.
- ▶ glyph, for specific font glyphs: the lowest bit (bit 0) is not set.
- ▶ ligature, for constructed ligatures bit 1 is set.

The glyph nodes also contain language data, split into four items that were current when the node was created: the `\setlanguage` (15 bits), `\lefthyphenmin` (8 bits), `\righthyphenmin` (8 bits), and `\uchyph` (1 bit).

Incidentally, Lua \TeX allows 16383 separate languages, and words can be 256 characters long. The language is stored with each character. You can set `\firstvalidlanguage` to for instance 1 and make thereby language 0 an ignored hyphenation language.

The new primitive `\hyphenationmin` can be used to signal the minimal length of a word. This value is stored with the (current) language.

Because the `\uchyph` value is saved in the actual nodes, its handling is subtly different from \TeX 82: changes to `\uchyph` become effective immediately, not at the end of the current partial paragraph.

Typeset boxes now always have their language information embedded in the nodes themselves, so there is no longer a possible dependency on the surrounding language settings. In \TeX 82, a mid-paragraph statement like `\unhbox0` would process the box using the current paragraph language unless there was a `\setlanguage` issued inside the box. In Lua \TeX , all language variables are already frozen.

In traditional \TeX the process of hyphenation is driven by `\lccodes`. In Lua \TeX we made this dependency less strong. There are several strategies possible. When you do nothing, the currently used `\lccodes` are used, when loading patterns, setting exceptions or hyphenating a list.

When you set `\savingshyphcodes` to a value greater than zero the current set of `\lccodes` will be saved with the language. In that case changing a `\lccode` afterwards has no effect. However, you can adapt the set with:

```
\hcode`a=`a
```

This change is global which makes sense if you keep in mind that the moment that hyphenation happens is (normally) when the paragraph or a horizontal box is constructed. When `\savingshyphcodes` was zero when the language got initialized you start out with nothing, otherwise you already have a set.

When a `\hcode` is greater than 0 but less than 32 is indicates the to be used length. In the following example we map a character (x) onto another one in the patterns and tell the engine that `æ` counts as two characters. Because traditionally zero itself is reserved for inhibiting hyphenation, a value of 32 counts as zero.

Here are some examples (we assume that French patterns are used):



```

foo-bar
\hcode `x=`o      foobar  foo-bar
\lefthyphenmin 3  fxxbar  fxx-bar
\lefthyphenmin 4  ædipus  ædi-pus
\hcode `æ=2       ædipus  ædipus
\hcode `i=32 \hcode `d=32  ædipus  ædipus

```

Carrying all this information with each glyph would give too much overhead and also make the process of setting up these codes more complex. A solution with hjcode sets was considered but rejected because in practice the current approach is sufficient and it would not be compatible anyway.

Beware: the values are always saved in the format, independent of the setting of \savingshyphcodes at the moment the format is dumped.

A boundary node normally would mark the end of a word which interferes with for instance discretionary injection. For this you can use the \wordboundary as a trigger. Here are a few examples of usage:

```
discrete---discrete
```

```

dis-
crete—
dis-
crete

```

```
discrete\discretionary{}{}{---}discrete
```

```

discrete
discrete

```

```
discrete\wordboundary\discretionary{}{}{---}discrete
```

```

dis-
crete
discrete

```

```
discrete\wordboundary\discretionary{}{}{---}\wordboundary discrete
```

```

dis-
crete
dis-
crete

```

```
discrete\wordboundary\discretionary{---}{}{} \wordboundary discrete
```

```

dis-
crete—
dis-
crete

```



We only accept an explicit hyphen when there is a preceding glyph and we skip a sequence of explicit hyphens since that normally indicates a -- or --- ligature in which case we can in a worse case usage get bad node lists later on due to messed up ligature building as these dashes are ligatures in base fonts. This is a side effect of separating the hyphenation, ligaturing and kerning steps.

The start and end of a sequence of characters is signalled by a glue, penalty, kern or boundary node. But by default also a hlist, vlist, rule, dir, whatsit, insert, and adjust node indicate a start or end. You can omit the last set from the test by setting flags in \hyphenationmode:

VALUE	BEHAVIOUR
	not strict
64	strict start
128	strict end
192	strict start and strict end

The word start is determined as follows:

NODE	BEHAVIOUR
boundary	yes when wordboundary
hlist	when the start bit is set
vlist	when the start bit is set
rule	when the start bit is set
dir	when the start bit is set
whatsit	when the start bit is set
glue	yes
math	skipped
glyph	exhyphenchar (one only) : yes (so no - —)
otherwise	yes

The word end is determined as follows:

NODE	BEHAVIOUR
boundary	yes
glyph	yes when different language
glue	yes
penalty	yes
kern	yes when not italic (for some historic reason)
hlist	when the end bit is set
vlist	when the end bit is set
rule	when the end bit is set
dir	when the end bit is set
whatsit	when the end bit is set
ins	when the end bit is set
adjust	when the end bit is set

Figures 7.1 upto 7.5 show some examples. In all cases we set the min values to 1 and make sure



that the words hyphenate at each character.

o-	o-	o-	o-
n-	n-	n-	n-
e	e	e	e
0	64	128	192

Figure 7.1 one

o-	o-	onet-	onet-
n-	n-	w-	w-
et-	et-	o	o
w-	w-		
o	o		
0	64	128	192

Figure 7.2 one\null two

o-	o-	onet-	onet-
n-	n-	w-	w-
et-	et-	o	o
w-	w-		
o	o		
0	64	128	192

Figure 7.3 \null one\null two

o-	o-	onetwo	onetwo
n-	n-		
et-	et-		
w-	w-		
o	o		
0	64	128	192

Figure 7.4 one\null two\null

o-	o-	onetwo	onetwo
n-	n-		
et-	et-		
w-	w-		
o	o		
0	64	128	192

Figure 7.5 \null one\null two\null

In traditional $\text{T}_{\text{E}}\text{X}$ ligature building and hyphenation are interwoven with the line break mechanism. In $\text{LuaT}_{\text{E}}\text{X}$ these phases are isolated. As a consequence we deal differently with (a sequence of) explicit hyphens. We already have added some control over aspects of the hyphenation and yet another one concerns automatic hyphens (e.g. - characters in the input).

Hyphenation and discretionary injection is driven by a mode parameter which is a bitset made



from the following values, some of which we saw in the previous examples.

1	honour (normal) <code>\discretionary's</code>
2	turn - into (automatic) discretionaries
4	turn <code>\-</code> into (explicit) discretionaries
8	hyphenate (syllable) according to language
16	hyphenate uppercase characters too (replaces <code>\uchyph</code>)
32	permit break at an explicit hyphen (border cases)
64	traditional \TeX compatibility wrt the start of a word
128	traditional \TeX compatibility wrt the end of a word
256	use <code>\automatichyphenpenalty</code>
512	use <code>\explicitthyphenpenalty</code>
1024	turn glue in discretionaries into kerns
2048	okay, let's be even more tolerant in discretionaries
4096	and again we're more permissive
16384	controls how successive explicit discretionaries are handled in base mode
8192	treat all discretionaries equal when breaking lines (in all three passes)
32768	kick in the handler (experiment)
65536	feedback compound snippets

Some of these options are still experimental, simply because not all aspects and side effects have been explored. You can find some experimental use cases in `Con \TeX t`.

7.3 The main control loop

In `Lua \TeX` 's main loop, almost all input characters that are to be typeset are converted into glyph node records with subtype 'character', but there are a few exceptions.

1. The `\accent` primitive creates nodes with subtype 'glyph' instead of 'character': one for the actual accent and one for the accentee. The primary reason for this is that `\accent` in \TeX 82 is explicitly dependent on the current font encoding, so it would not make much sense to attach a new meaning to the primitive's name, as that would invalidate many old documents and macro packages. A secondary reason is that in \TeX 82, `\accent` prohibits hyphenation of the current word. Since in `Lua \TeX` hyphenation only takes place on 'character' nodes, it is possible to achieve the same effect. Of course, modern Unicode aware macro packages will not use the `\accent` primitive at all but try to map directly on composed characters. This change of meaning did happen with `\char`, that now generates 'glyph' nodes with a character subtype. In traditional \TeX there was a strong relationship between the 8-bit input encoding, hyphenation and glyphs taken from a font. In `Lua \TeX` we have utf input, and in most cases this maps directly to a character in a font, apart from glyph replacement in the font engine. If you want to access arbitrary glyphs in a font directly you can always use Lua to do so, because fonts are available as Lua table.
2. All the results of processing in math mode eventually become nodes with 'glyph' subtypes. In fact, the result of processing math is just a regular list of glyphs, kerns, glue, penalties, boxes etc.
3. Automatic discretionaries are handled differently. \TeX 82 inserts an empty discretionary after



sensing an input character that matches the `\hyphenchar` in the current font. This test is wrong in our opinion: whether or not hyphenation takes place should not depend on the current font, it is a language property.⁴

In LuaTeX, it works like this: if LuaTeX senses a string of input characters that matches the value of the new integer parameter `\exhyphenchar`, it will insert an explicit discretionary after that series of nodes. Initially TeX sets the `\exhyphenchar=-1`. Incidentally, this is a global parameter instead of a language-specific one because it may be useful to change the value depending on the document structure instead of the text language.

The insertion of discretionaries after a sequence of explicit hyphens happens at the same time as the other hyphenation processing, *not* inside the main control loop.

The only use LuaTeX has for `\hyphenchar` is at the check whether a word should be considered for hyphenation at all. If the `\hyphenchar` of the font attached to the first character node in a word is negative, then hyphenation of that word is abandoned immediately. This behaviour is added for backward compatibility only, and the use of `\hyphenchar=-1` as a means of preventing hyphenation should not be used in new LuaTeX documents.

4. The `\setlanguage` command no longer creates whatsits. The meaning of `\setlanguage` is changed so that it is now an integer parameter like all others. That integer parameter is used in `\glyph_node` creation to add language information to the glyph nodes. In conjunction, the `\language` primitive is extended so that it always also updates the value of `\setlanguage`.
5. The `\noundary` command (that prohibits word boundary processing where that would normally take place) now does create nodes. These nodes are needed because the exact place of the `\noundary` command in the input stream has to be retained until after the ligature and font processing stages.
6. There is no longer a `main_loop` label in the code. Remember that TeX82 did quite a lot of processing while adding `char_nodes` to the horizontal list? For speed reasons, it handled that processing code outside of the ‘main control’ loop, and only the first character of any ‘word’ was handled by that ‘main control’ loop. In LuaTeX, there is no longer a need for that (all hard work is done later), and the (now very small) bits of character-handling code have been moved back inline. When `\tracingcommands` is on, this is visible because the full word is reported, instead of just the initial character.

Because we tend to make hard coded behaviour configurable a few new primitives have been added:

```
\hyphenpenaltymode
\automatichyphenpenalty
\explicithyphenpenalty
```

The usage of these penalties is controlled by the `\hyphenationmode` flags 256 and 512 and when these are not set `\exhyphenpenalty` is used.

You can use the `\tracinghyphenation` variable to get a bit more information about what happens.

⁴ When TeX showed up we didn't have Unicode yet and being limited to eight bits meant that one sometimes had to compromise between supporting character input, glyph rendering, hyphenation.



VALUE	EFFECT
1	report redundant pattern (happens by default in LuaTeX)
2	report words that reach the hyphenator and got treated
3	show the result of a hyphenated word (a node list)

7.4 Loading patterns and exceptions

Although we keep the traditional approach towards hyphenation (which is still superior) the implementation of the hyphenation algorithm in LuaTeX is quite different from the one in TeX82.

After expansion, the argument for `\patterns` has to be proper utf8 with individual patterns separated by spaces, no `\char` or `\chardef` commands are allowed. The current implementation is quite strict and will reject all non-Unicode characters. Likewise, the expanded argument for `\hyphenation` also has to be proper utf8, but here a bit of extra syntax is provided:

1. Three sets of arguments in curly braces (`{ } { } { }`) indicate a desired complex discretionary, with arguments as in `\discretionary`'s command in normal document input.
2. A `-` indicates a desired simple discretionary, cf. `\-` and `\discretionary{-}{ } { }` in normal document input.
3. Internal command names are ignored. This rule is provided especially for `\discretionary`, but it also helps to deal with `\relax` commands that may sneak in.
4. An `=` indicates a (non-discretionary) hyphen in the document input.

The expanded argument is first converted back to a space-separated string while dropping the internal command names. This string is then converted into a dictionary by a routine that creates key-value pairs by converting the other listed items. It is important to note that the keys in an exception dictionary can always be generated from the values. Here are a few examples:

VALUE	IMPLIED KEY (INPUT)	EFFECT
<code>ta-ble</code>	<code>table</code>	<code>ta\ble (= ta\discretionary{-}{ } { }ble)</code>
<code>ba{k-}{ } {c}ken</code>	<code>backen</code>	<code>ba\discretionary{k-}{ } {c}ken</code>

The resultant patterns and exception dictionary will be stored under the language code that is the present value of `\language`.

In the last line of the table, you see there is no `\discretionary` command in the value: the command is optional in the TeX-based input syntax. The underlying reason for that is that it is conceivable that a whole dictionary of words is stored as a plain text file and loaded into LuaTeX using one of the functions in the Lua language library. This loading method is quite a bit faster than going through the TeX language primitives, but some (most?) of that speed gain would be lost if it had to interpret command sequences while doing so.

It is possible to specify extra hyphenation points in compound words by using `{-}{ } {-}` for the explicit hyphen character (replace `-` by the actual explicit hyphen character if needed). For example, this matches the word ‘multi-word-boundaries’ and allows an extra break inbetween ‘boun’ and ‘daries’:

```
\hyphenation{multi{-}{ } {-}word{-}{ } {-}boun-daries}
```



The motivation behind the ϵ -TeX extension `\savingsyhphcodes` was that hyphenation heavily depended on font encodings. This is no longer true in LuaTeX, and the corresponding primitive is basically ignored. Because we now have `\hjcode`, the case related codes can be used exclusively for `\uppercase` and `\lowercase`.

The three curly brace pair pattern in an exception can be somewhat unexpected so we will try to explain it by example. The pattern `foo{}{}{x}bar` pattern creates a lookup `fooxbar` and the pattern `foo{}{}{}bar` creates `foobar`. Then, when a hit happens there is a replacement text (x) or none. Because we introduced penalties in discretionary nodes, the exception syntax now also can take a penalty specification. The value between square brackets is a multiplier for `\exceptionpenalty`. Here we have set it to 10000 so effectively we get 30000 in the example.

<code>x{a-}{-b}{}x{a-}{-b}{}x{a-}{-b}{}x{a-}{-b}{}xx</code>			
10em	3em	0em	6em
123 xxxxxx 123	123 xxa- -bxa- -bxa- -bxx 123	123 xa- -bxa- -bxa- -bxa- -bxx 123	123 xxxxxx xxxxxx xxa- -bxxxx xxa- -bxxxx 123

<code>x{a-}{-b}{}x{a-}{-b}{}[3]x{a-}{-b}{}[1]x{a-}{-b}{}xx</code>			
10em	3em	0em	6em
123 xxxxxx 123	123 xa- -bxxxxa- -bxx 123	123 xa- -bxxxxa- -bxx 123	123 xxxxa- -bxx xxxxxx xxxxxxx xa- -bxxxxxx 123

<code>z{a-}{-b}{z}{a-}{-b}{z}{a-}{-b}{z}{a-}{-b}{z}z</code>			
10em	3em	0em	6em
123 zzzzzz 123	123 za- -bza- -bza- -b 123	123 za- -bza- -bza- -b a- -b23	123 zzzzzz zzzzzz zzza- -bzz zzzzzz 123



z{a-}{-b}{z}{a-}{-b}{z}[3]{a-}{-b}{z}[1]{a-}{-b}{z}z			
10em	3em	0em	6em
123 zzzzzz 123	123 za- -bzzzz 123	123 za- -bzzzz a- -b23	123 zzzzzz zzzzzz za- -bzzzz a- -bzzzzz 123

7.5 Applying hyphenation

The internal structures Lua \TeX uses for the insertion of discretionary hyphenation marks in words is very different from the ones in \TeX 82, and that means there are some noticeable differences in handling as well.

First and foremost, there is no ‘compressed trie’ involved in hyphenation. The algorithm still reads pattern files generated by Patgen, but Lua \TeX uses a finite state hash to match the patterns against the word to be hyphenated. This algorithm is based on the ‘libhunj’ library used by OpenOffice, which in turn is inspired by \TeX .

There are a few differences between Lua \TeX and \TeX 82 that are a direct result of the implementation:

- ▶ Lua \TeX happily hyphenates the full Unicode character range.
- ▶ Pattern and exception dictionary size is limited by the available memory only, all allocations are done dynamically. The trie-related settings in `texmf.cnf` are ignored.
- ▶ Because there is no ‘trie preparation’ stage, language patterns never become frozen. This means that the primitive `\patterns` (and its Lua counterpart `language.patterns`) can be used at any time, not only in `ini \TeX` .
- ▶ Only the string representation of `\patterns` and `\hyphenation` is stored in the format file. At format load time, they are simply re-evaluated. It follows that there is no real reason to preload languages in the format file. In fact, it is usually not a good idea to do so. It is much smarter to load patterns no sooner than the first time they are actually needed.
- ▶ Lua \TeX uses the language-specific variables `\prehyphenchar` and `\posthyphenchar` in the creation of implicit discretionary hyphenation marks, instead of \TeX 82’s `\hyphenchar`, and the values of the language-specific variables `\preexhyphenchar` and `\postexhyphenchar` for explicit discretionary hyphenation marks (instead of \TeX 82’s empty discretionary).
- ▶ The value of the two counters related to hyphenation, `\hyphenpenalty` and `\exhyphenpenalty`, are now stored in the discretionary nodes. This permits a local overload for explicit `\discretionary` commands. The value current when the hyphenation pass is applied is used. When no callbacks are used this is compatible with traditional \TeX . When you apply the Lua `language.hyphenate` function the current values are used.
- ▶ The hyphenation exception dictionary is maintained as key-value hash, and that is also dynamic, so the `hyph_size` setting is not used either.

Because we store penalties in the disc node the `\discretionary` command has been extended to accept an optional penalty specification, so you can do the following:



```

\hsizelmm
1:foo{\hyphenpenalty 10000\discretionary{}{}{}}bar\par
2:foo\discretionary penalty 10000 {}{}{}}bar\par
3:foo\discretionary{}{}{}}bar\par

```

This results in:

```

1:foobar
2:foobar
3:foo
bar

```

Inserted characters and ligatures inherit their attributes from the nearest glyph node item (usually the preceding one, but the following one for the items inserted at the left-hand side of a word).

Word boundaries are no longer implied by font switches, but by language switches. One word can have two separate fonts and still be hyphenated correctly (but it can not have two different languages, the `\setlanguage` command forces a word boundary).

All languages start out with `\prehyphenchar=\-`, `\posthyphenchar=0`, `\preexhyphenchar=0` and `\postexhyphenchar=0`. When you assign the values of one of these four parameters, you are actually changing the settings for the current `\language`, this behaviour is compatible with `\patterns` and `\hyphenation`.

LuaTeX also hyphenates the first word in a paragraph. Words can be up to 256 characters long (up from 64 in TeX82). Longer words are ignored right now, but eventually either the limitation will be removed or perhaps it will become possible to silently ignore the excess characters (this is what happens in TeX82, but there the behaviour cannot be controlled).

If you are using the Lua function `language.hyphenate`, you should be aware that this function expects to receive a list of ‘character’ nodes. It will not operate properly in the presence of ‘glyph’, ‘ligature’, or ‘ghost’ nodes, nor does it know how to deal with kerning.

7.6 Applying ligatures and kerning

After all possible hyphenation points have been inserted in the list, LuaTeX will process the list to convert the ‘character’ nodes into ‘glyph’ and ‘ligature’ nodes. This is actually done in two stages: first all ligatures are processed, then all kerning information is applied to the result list. But those two stages are somewhat dependent on each other: If the used font makes it possible to do so, the ligaturing stage adds virtual ‘character’ nodes to the word boundaries in the list. While doing so, it removes and interprets `\noboundary` nodes. The kerning stage deletes those word boundary items after it is done with them, and it does the same for ‘ghost’ nodes. Finally, at the end of the kerning stage, all remaining ‘character’ nodes are converted to ‘glyph’ nodes.

This separation is worth mentioning because, if you overrule from Lua only one of the two callbacks related to font handling, then you have to make sure you perform the tasks normally done by LuaTeX itself in order to make sure that the other, non-overruled, routine continues to function properly.



Although we could improve the situation the reality is that in modern OpenType fonts ligatures can be constructed in many ways: by replacing a sequence of characters by one glyph, or by selectively replacing individual glyphs, or by kerning, or any combination of this. Add to that contextual analysis and it will be clear that we have to let Lua do that job instead. The generic font handler that we provide (which is part of ConT_EXt) distinguishes between base mode (which essentially is what we describe here and which delegates the task to T_EX) and node mode (which deals with more complex fonts).

In so called base mode, where T_EX does the work, the ligature construction (normally) goes in small steps. An f followed by an f becomes an ff ligatures and that one followed by an i can become a ffi ligature. The situation can be complicated by hyphenation points between these characters. When there are several in a ligature collapsing happens. Flag "4000 in the \hyphenationmode variable determines if this happens lazy or greedy, i.e. the first hyphen wins or the last one does. In practice a ConT_EXt user won't have to deal with this because most fonts are processed in node mode.

7.7 Breaking paragraphs into lines

This code is almost unchanged, but because of the above-mentioned changes with respect to discretionaries and ligatures, line breaking will potentially be different from traditional T_EX. The actual line breaking code is still based on the T_EX82 algorithms, and there can be no discretionaries inside of discretionaries. But, as patterns evolve and font handling can influence discretionaries, you need to be aware of the fact that long term consistency is not an engine matter only.

But that situation is now fairly common in LuaT_EX, due to the changes to the ligaturing mechanism. And also, the LuaT_EX discretionary nodes are implemented slightly different from the T_EX82 nodes: the no_break text is now embedded inside the disc node, where previously these nodes kept their place in the horizontal list. In traditional T_EX the discretionary node contains a counter indicating how many nodes to skip, but in LuaT_EX we store the pre, post and replace text in the discretionary node.

The combined effect of these two differences is that LuaT_EX does not always use all of the potential breakpoints in a paragraph, especially when fonts with many ligatures are used. Of course kerning also complicates matters here.

7.8 The language library

7.8.1 new and id

This library provides the interface to LuaT_EX's structure representing a language, and the associated functions.

```
<language> l = language.new()  
<language> l = language.new(<number> id)
```

This function creates a new userdata object. An object of type <language> is the first argument



to most of the other functions in the language library. These functions can also be used as if they were object methods, using the colon syntax. Without an argument, the next available internal id number will be assigned to this object. With argument, an object will be created that links to the internal language with that id number.

```
<number> n = language.id(<language> l)
```

The number returned is the internal \language id number this object refers to.

7.8.2 hyphenation

You can load exceptions with:

```
<string> n = language.hyphenation(<language> l)
language.hyphenation(<language> l, <string> n)
```

When no string is given (the first example) a string with all exceptions is returned.

7.8.3 clearhyphenation and clean

This either returns the current hyphenation exceptions for this language, or adds new ones. The syntax of the string is explained in section 7.4.

```
language.clearhyphenation(<language> l)
```

This call clears the exception dictionary (string) for this language.

```
<string> n = language.clean(<language> l, <string> o)
<string> n = language.clean(<string> o)
```

This function creates a hyphenation key from the supplied hyphenation value. The syntax of the argument string is explained in section 7.4. This function is useful if you want to do something else based on the words in a dictionary file, like spell-checking.

7.8.4 patterns and clearpatterns

```
<string> n = language.patterns(<language> l)
language.patterns(<language> l, <string> n)
```

This adds additional patterns for this language object, or returns the current set. The syntax of this string is explained in section 7.4.

```
language.clearpatterns(<language> l)
```

This can be used to clear the pattern dictionary for a language.



7.8.5 hyphenationmin

This function sets (or gets) the value of the TeX parameter `\hyphenationmin`.

```
n = language.hyphenationmin(<language> l)
language.hyphenationmin(<language> l, <number> n)
```

7.8.6 [pre|post][ex|]hyphenchar

```
<number> n = language.prehyphenchar(<language> l)
language.prehyphenchar(<language> l, <number> n)
```

```
<number> n = language.posthyphenchar(<language> l)
language.posthyphenchar(<language> l, <number> n)
```

These two are used to get or set the ‘pre-break’ and ‘post-break’ hyphen characters for implicit hyphenation in this language. The initial values are decimal 45 (hyphen) and decimal 0 (indicating emptiness).

```
<number> n = language.preexhyphenchar(<language> l)
language.preexhyphenchar(<language> l, <number> n)
```

```
<number> n = language.postexhyphenchar(<language> l)
language.postexhyphenchar(<language> l, <number> n)
```

These gets or set the ‘pre-break’ and ‘post-break’ hyphen characters for explicit hyphenation in this language. Both are initially decimal 0 (indicating emptiness).

7.8.7 hyphenate

The next call inserts hyphenation points (discretionary nodes) in a node list. If `tail` is given as argument, processing stops on that node. Currently, success is always true if `head` (and `tail`, if specified) are proper nodes, regardless of possible other errors.

```
<boolean> success = language.hyphenate(<node> head)
<boolean> success = language.hyphenate(<node> head, <node> tail)
```

Hyphenation works only on ‘characters’, a special subtype of all the glyph nodes with the node subtype having the value 1. Glyph modes with different subtypes are not processed. See section 7.2 for more details.

7.8.8 [set|get]hjcode

The following two commands can be used to set or query hj codes:

```
language.sethjcode(<language> l, <number> char, <number> usedchar)
<number> usedchar = language.gethjcode(<language> l, <number> char)
```



When you set a hrcode the current sets get initialized unless the set was already initialized due to \savingsphcodes being larger than zero.





8 Math

8.1 Traditional alongside OpenType

At this point there is no difference between LuaMetaT_EX and LuaT_EX with respect to math. The handling of mathematics in LuaT_EX differs quite a bit from how T_EX82 (and therefore pdfT_EX) handles math. First, LuaT_EX adds primitives and extends some others so that Unicode input can be used easily. Second, all of T_EX82's internal special values (for example for operator spacing) have been made accessible and changeable via control sequences. Third, there are extensions that make it easier to use OpenType math fonts. And finally, there are some extensions that have been proposed or considered in the past that are now added to the engine.

8.2 Unicode math characters

Character handling is now extended up to the full Unicode range (the `\U` prefix), which is compatible with X_YT_EX.

The math primitives from T_EX are kept as they are, except for the ones that convert from input to math commands: `\mathcode`, and `\delcode`. These two now allow for a 21-bit character argument on the left hand side of the equals sign.

Some of the new LuaT_EX primitives read more than one separate value. This is shown in the tables below by a plus sign.

The input for such primitives would look like this:

```
\def\overbrace{\Umathaccent 0 1 "23DE }
```

The altered T_EX82 primitives are:

PRIMITIVE	MIN	MAX	MIN	MAX
<code>\mathcode</code>	0	10FFFF	= 0	8000
<code>\delcode</code>	0	10FFFF	= 0	FFFFFF

The unaltered ones are:

PRIMITIVE	MIN	MAX
<code>\mathchardef</code>	0	8000
<code>\mathchar</code>	0	7FFF
<code>\mathaccent</code>	0	7FFF
<code>\delimiter</code>	0	7FFFFFFF
<code>\radical</code>	0	7FFFFFFF

For practical reasons `\mathchardef` will silently accept values larger than `0x8000` and interpret it as `\Umathcharnumdef`. This is needed to satisfy older macro packages.

The following new primitives are compatible with X_YT_EX:



PRIMITIVE	MIN	MAX	MIN	MAX
<code>\Umathchardef</code>	0+0+0	7+FF+10FFFF		
<code>\Umathcharnumdef⁵</code>	-80000000	7FFFFFFF		
<code>\Umathcode</code>	0	10FFFF	= 0+0+0	7+FF+10FFFF
<code>\Udelcode</code>	0	10FFFF	= 0+0	FF+10FFFF
<code>\Umathchar</code>	0+0+0	7+FF+10FFFF		
<code>\Umathaccent</code>	0+0+0	7+FF+10FFFF		
<code>\Udelimiter</code>	0+0+0	7+FF+10FFFF		
<code>\Uradical</code>	0+0	FF+10FFFF		
<code>\Umathcharnum</code>	-80000000	7FFFFFFF		
<code>\Umathcodenum</code>	0	10FFFF	= -80000000	7FFFFFFF
<code>\Udelcodenum</code>	0	10FFFF	= -80000000	7FFFFFFF

Specifications typically look like:

```
\Umathchardef\xx="1"0"456
\Umathcode 123="1"0"789
```

The new primitives that deal with delimiter-style objects do not set up a ‘large family’. Selecting a suitable size for display purposes is expected to be dealt with by the font via the `\Umathoperatorsizer` parameter.

For some of these primitives, all information is packed into a single signed integer. For the first two (`\Umathcharnum` and `\Umathcodenum`), the lowest 21 bits are the character code, the 3 bits above that represent the math class, and the family data is kept in the topmost bits. This means that the values for math families 128–255 are actually negative. For `\Udelcodenum` there is no math class. The math family information is stored in the bits directly on top of the character code. Using these three commands is not as natural as using the two- and three-value commands, so unless you know exactly what you are doing and absolutely require the speedup resulting from the faster input scanning, it is better to use the verbose commands instead.

The `\Umathaccent` command accepts optional keywords to control various details regarding math accents. See section 8.6.2 below for details.

There are more new primitives and all of these will be explained in following sections:

PRIMITIVE	VALUE RANGE (IN HEX)
<code>\Uroot</code>	0 + 0-FF + 10FFFF
<code>\Uoverdelimiter</code>	0 + 0-FF + 10FFFF
<code>\Uunderdelimiter</code>	0 + 0-FF + 10FFFF
<code>\Udelimiterover</code>	0 + 0-FF + 10FFFF
<code>\Udelimiterunder</code>	0 + 0-FF + 10FFFF



8.3 Math styles

8.3.1 `\mathstyle`

It is possible to discover the math style that will be used for a formula in an expandable fashion (while the math list is still being read). To make this possible, LuaTeX adds the new primitive: `\mathstyle`. This is a 'convert command' like e.g. `\romannumeral`: its value can only be read, not set. Beware that contrary to LuaTeX this is now a proper number so you need to use `\number` or `\the` in order to serialize it.

The returned value is between 0 and 7 (in math mode), or -1 (all other modes). For easy testing, the eight math style commands have been altered so that they can be used as numeric values, so you can write code like this:

```
\ifnum\mathstyle=\textstyle
  \message{normal text style}
\else \ifnum\mathstyle=\crampedtextstyle
  \message{cramped text style}
\fi \fi
```

Sometimes you won't get what you expect so a bit of explanation might help to understand what happens. When math is parsed and expanded it gets turned into a linked list. In a second pass the formula will be build. This has to do with the fact that in order to determine the automatically chosen sizes (in for instance fractions) following content can influence preceding sizes. A side effect of this is for instance that one cannot change the definition of a font family (and thereby reusing numbers) because the number that got used is stored and used in the second pass (so changing `\fam 12` mid-formula spoils over to preceding use of that family).

The style switching primitives like `\textstyle` are turned into nodes so the styles set there are frozen. The `\mathchoice` primitive results in four lists being constructed of which one is used in the second pass. The fact that some automatic styles are not yet known also means that the `\mathstyle` primitive expands to the current style which can of course be different from the one really used. It's a snapshot of the first pass state. As a consequence in the following example you get a style number (first pass) typeset that can actually differ from the used style (second pass). In the case of a math choice used ungrouped, the chosen style is used after the choice too, unless you group.

```
[a:\number\mathstyle]\quad
\bgroup
\mathchoice
  {\bf \scriptstyle      (x:d :\number\mathstyle)}
  {\bf \scriptscriptstyle (x:t :\number\mathstyle)}
  {\bf \scriptscriptstyle (x:s :\number\mathstyle)}
  {\bf \scriptscriptstyle (x:ss:\number\mathstyle)}
\egroup
\quad[b:\number\mathstyle]\quad
\mathchoice
  {\bf \scriptstyle      (y:d :\number\mathstyle)}
```



```

{\bf \scriptscriptstyle (y:t :\number\mathstyle)}
{\bf \scriptscriptstyle (y:s :\number\mathstyle)}
{\bf \scriptscriptstyle (y:ss:\number\mathstyle)}
\quad[c:\number\mathstyle]\quad
\bgroup
\mathchoice
{\bf \scriptstyle (z:d :\number\mathstyle)}
{\bf \scriptscriptstyle (z:t :\number\mathstyle)}
{\bf \scriptscriptstyle (z:s :\number\mathstyle)}
{\bf \scriptscriptstyle (z:ss:\number\mathstyle)}
\egroup
\quad[d:\number\mathstyle]

```

This gives:

$$[a : 0] \quad (\mathbf{x:d:4}) \quad [b : 0] \quad (\mathbf{y:d:4}) \quad [c:0] \quad (\mathbf{z:s:6}) \quad [d:0]$$

$$[a : 2] \quad (\mathbf{x:t:6}) \quad [b : 2] \quad (\mathbf{y:t:6}) \quad [c:2] \quad (\mathbf{z:ss:6}) \quad [d:2]$$

Using `\begingroup ... \endgroup` instead gives:

$$[a : 0] \quad (\mathbf{x:d:4}) \quad [b:0] \quad (\mathbf{y:s:6}) \quad [c:0] \quad (\mathbf{z:ss:6}) \quad [d:0]$$

$$[a : 2] \quad (\mathbf{x:t:6}) \quad [b:2] \quad (\mathbf{y:ss:6}) \quad [c:2] \quad (\mathbf{z:ss:6}) \quad [d:2]$$

This might look wrong but it's just a side effect of `\mathstyle` expanding to the current (first pass) style and the number being injected in the list that gets converted in the second pass. It all makes sense and it illustrates the importance of grouping. In fact, the math choice style being effective afterwards has advantages. It would be hard to get it otherwise.

8.3.2 `\Ustack`

There are a few math commands in \TeX where the style that will be used is not known straight from the start. These commands (`\over`, `\atop`, `\overwithdelims`, `\atopwithdelims`) would therefore normally return wrong values for `\mathstyle`. To fix this, $\text{Lua}\TeX$ introduces a special prefix command: `\Ustack`:

$$\math{\Ustack {a \over b}}$$

The `\Ustack` command will scan the next brace and start a new math group with the correct (numerator) math style.

8.3.3 The new `\cramped ...style` commands

$\text{Lua}\TeX$ has four new primitives to set the cramped math styles directly:

```

\crampeddisplaystyle
\crampedtextstyle

```



`\crampedscriptstyle`
`\crampedscriptscriptstyle`

These additional commands are not all that valuable on their own, but they come in handy as arguments to the math parameter settings that will be added shortly.

In Eijkhouts “ \TeX by Topic” the rules for handling styles in scripts are described as follows:

- ▶ In any style superscripts and subscripts are taken from the next smaller style. Exception: in display style they are in script style.
- ▶ Subscripts are always in the cramped variant of the style; superscripts are only cramped if the original style was cramped.
- ▶ In an `.. \over ..` formula in any style the numerator and denominator are taken from the next smaller style.
- ▶ The denominator is always in cramped style; the numerator is only in cramped style if the original style was cramped.
- ▶ Formulas under a `\sqrt` or `\overline` are in cramped style.

In $\text{Lua}\TeX$ one can set the styles in more detail which means that you sometimes have to set both normal and cramped styles to get the effect you want. (Even) if we force styles in the script using `\scriptstyle` and `\crampedscriptstyle` we get this:

STYLE	EXAMPLE
default	$b^{x=xx}$ $x_{x=xx}$
script	$b^{x=xx}$ $x_{x=xx}$
crampedscript	$b^{x=xx}$ $x_{x=xx}$

Now we set the following parameters

```
\Umathordrelspacing\scriptstyle=30mu
\Umathordordspacing\scriptstyle=30mu
```

This gives a different result:

STYLE	EXAMPLE
default	$b^x =x \ x$ $x_{x=xx}$
script	$b^x =x \ x$ $x_x =x \ x$
crampedscript	$b^{x=xx}$ $x_{x=xx}$

But, as this is not what is expected (visually) we should say:

```
\Umathordrelspacing\scriptstyle=30mu
\Umathordordspacing\scriptstyle=30mu
\Umathordrelspacing\crampedscriptstyle=30mu
\Umathordordspacing\crampedscriptstyle=30mu
```

Now we get:



STYLE	EXAMPLE
default	$b_x^x =_x x$
script	$b_x^x =_x x$
crampedscript	$b_x^x =_x x$

8.4 Math parameter settings

8.4.1 Many new `\Umath*` primitives

In LuaTeX, the font dimension parameters that TeX used in math typesetting are now accessible via primitive commands. In fact, refactoring of the math engine has resulted in turning some hard codes properties into parameters.

PRIMITIVE NAME	DESCRIPTION
<code>\Umathquad</code>	the width of 18 mu's
<code>\Umathaxis</code>	height of the vertical center axis of the math formula above the baseline
<code>\Umathoperatorsize</code>	minimum size of large operators in display mode
<code>\Umathoverbarkern</code>	vertical clearance above the rule
<code>\Umathoverbarrule</code>	the width of the rule
<code>\Umathoverbarvgap</code>	vertical clearance below the rule
<code>\Umathunderbarkern</code>	vertical clearance below the rule
<code>\Umathunderbarrule</code>	the width of the rule
<code>\Umathunderbarvgap</code>	vertical clearance above the rule
<code>\Umathradicalkern</code>	vertical clearance above the rule
<code>\Umathradicalrule</code>	the width of the rule
<code>\Umathradicalvgap</code>	vertical clearance below the rule
<code>\Umathradicaldegreebefore</code>	the forward kern that takes place before placement of the radical degree
<code>\Umathradicaldegreeafter</code>	the backward kern that takes place after placement of the radical degree
<code>\Umathradicaldegreeraise</code>	this is the percentage of the total height and depth of the radical sign that the degree is raised by; it is expressed in percents, so 60% is expressed as the integer 60
<code>\Umathstackvgap</code>	vertical clearance between the two elements in an <code>\atop</code> stack
<code>\Umathstacknumup</code>	numerator shift upward in <code>\atop</code> stack
<code>\Umathstackdenomdown</code>	denominator shift downward in <code>\atop</code> stack
<code>\Umathfractionrule</code>	the width of the rule in a <code>\over</code>
<code>\Umathfractionnumvgap</code>	vertical clearance between the numerator and the rule
<code>\Umathfractionnumup</code>	numerator shift upward in <code>\over</code>
<code>\Umathfractiondenomvgap</code>	vertical clearance between the denominator and the rule
<code>\Umathfractiondenomdown</code>	denominator shift downward in <code>\over</code>
<code>\Umathfractiondelsize</code>	minimum delimiter size for <code>\dots</code> withdelims
<code>\Umathlimitabovevgap</code>	vertical clearance for limits above operators



<code>\Umathlimitabovebgap</code>	vertical baseline clearance for limits above operators
<code>\Umathlimitabovekern</code>	space reserved at the top of the limit
<code>\Umathlimitbelowvgap</code>	vertical clearance for limits below operators
<code>\Umathlimitbelowbgap</code>	vertical baseline clearance for limits below operators
<code>\Umathlimitbelowkern</code>	space reserved at the bottom of the limit
<code>\Umathoverdelimitervgap</code>	vertical clearance for limits above delimiters
<code>\Umathoverdelimiterbgap</code>	vertical baseline clearance for limits above delimiters
<code>\Umathunderdelimitervgap</code>	vertical clearance for limits below delimiters
<code>\Umathunderdelimeterbgap</code>	vertical baseline clearance for limits below delimiters
<code>\Umathsubshiftdrop</code>	subscript drop for boxes and subformulas
<code>\Umathsubshiftdown</code>	subscript drop for characters
<code>\Umathsupshiftdrop</code>	superscript drop (raise, actually) for boxes and subformulas
<code>\Umathsupshiftpup</code>	superscript raise for characters
<code>\Umathsubsupshiftdown</code>	subscript drop in the presence of a superscript
<code>\Umathsubtopmax</code>	the top of standalone subscripts cannot be higher than this above the baseline
<code>\Umathsupbottommin</code>	the bottom of standalone superscripts cannot be less than this above the baseline
<code>\Umathsupsubbottommax</code>	the bottom of the superscript of a combined super- and subscript be at least as high as this above the baseline
<code>\Umathsubsupvgap</code>	vertical clearance between super- and subscript
<code>\Umathspacebeforescript</code>	additional space added before a super- or subprescript (bonus setting)
<code>\Umathspaceafterscript</code>	additional space added after a super- or subscript
<code>\Umathconnectoroverlapmin</code>	minimum overlap between parts in an extensible recipe

Each of the parameters in this section can be set by a command like this:

```
\Umathquad\displaystyle=1em
```

they obey grouping, and you can use `\the\Umathquad\displaystyle` if needed.

8.4.2 Font-based math parameters

While it is nice to have these math parameters available for tweaking, it would be tedious to have to set each of them by hand. For this reason, LuaTeX initializes a bunch of these parameters whenever you assign a font identifier to a math family based on either the traditional math font dimensions in the font (for assignments to math family 2 and 3 using tfm-based fonts like `cmsy` and `cmex`), or based on the named values in a potential `MathConstants` table when the font is loaded via Lua. If there is a `MathConstants` table, this takes precedence over font dimensions, and in that case no attention is paid to which family is being assigned to: the `MathConstants` tables in the last assigned family sets all parameters.

In the table below, the one-letter style abbreviations and symbolic tfm font dimension names match those used in the `TEXbook`. Assignments to `\textfont` set the values for the cramped and uncramped display and text styles, `\scriptfont` sets the script styles, and `\scriptscriptfont` sets the scriptscript styles, so we have eight parameters for three font sizes. In the tfm case,



assignments only happen in family 2 and family 3 (and of course only for the parameters for which there are font dimensions).

Besides the parameters below, LuaTeX also looks at the ‘space’ font dimension parameter. For math fonts, this should be set to zero.

VARIABLE / STYLE	TFM / OPENTYPE
$\backslash\Umathaxis$	axis_height AxisHeight
⁶ $\backslash\Umathoperator\size$ D, D'	– DisplayOperatorMinHeight
⁹ $\backslash\Umathfraction\del\size$ D, D'	delim1 FractionDelimiterDisplayStyleSize
⁹ $\backslash\Umathfraction\del\size$ T, T', S, S', SS, SS'	delim2 FractionDelimiterSize
$\backslash\Umathfraction\denom\down$ D, D'	denom1 FractionDenominatorDisplayStyleShiftDown
$\backslash\Umathfraction\denom\down$ T, T', S, S', SS, SS'	denom2 FractionDenominatorShiftDown
$\backslash\Umathfraction\denom\vgap$ D, D'	3*default_rule_thickness FractionDenominatorDisplayStyleGapMin
$\backslash\Umathfraction\denom\vgap$ T, T', S, S', SS, SS'	default_rule_thickness FractionDenominatorGapMin
$\backslash\Umathfraction\num\up$ D, D'	num1 FractionNumeratorDisplayStyleShiftUp
$\backslash\Umathfraction\num\up$ T, T', S, S', SS, SS'	num2 FractionNumeratorShiftUp
$\backslash\Umathfraction\num\vgap$ D, D'	3*default_rule_thickness FractionNumeratorDisplayStyleGapMin
$\backslash\Umathfraction\num\vgap$ T, T', S, S', SS, SS'	default_rule_thickness FractionNumeratorGapMin
$\backslash\Umathfraction\rule$	default_rule_thickness FractionRuleThickness
$\backslash\Umathskewed\fraction\hgap$	math_quad/2 SkewedFractionHorizontalGap
$\backslash\Umathskewed\fraction\vgap$	math_x_height SkewedFractionVerticalGap
$\backslash\Umathlimit\above\bgap$	big_op_spacing3 UpperLimitBaselineRiseMin
¹ $\backslash\Umathlimit\above\kern$	big_op_spacing5 0
$\backslash\Umathlimit\above\vgap$	big_op_spacing1 UpperLimitGapMin
$\backslash\Umathlimit\below\bgap$	big_op_spacing4



	LowerLimitBaselineDropMin
¹ \Umathlimitbelowkern	big_op_spacing5 0
\Umathlimitbelowvgap	big_op_spacing2 LowerLimitGapMin
\Umathoverdelimitervgap	big_op_spacing1 StretchStackGapBelowMin
\Umathoverdelimiterbgap	big_op_spacing3 StretchStackTopShiftUp
\Umathunderdelimitervgap	big_op_spacing2 StretchStackGapAboveMin
\Umathunderdelimiterbgap	big_op_spacing4 StretchStackBottomShiftDown
\Umathoverbarkern	default_rule_thickness OverbarExtraAscender
\Umathoverbarrule	default_rule_thickness OverbarRuleThickness
\Umathoverbarvgap	3*default_rule_thickness OverbarVerticalGap
¹ \Umathquad	math_quad <font_size(f)>
\Umathradicalkern	default_rule_thickness RadicalExtraAscender
² \Umathradicalrule	<not set> RadicalRuleThickness
³ \Umathradicalvgap D, D'	default_rule_thickness+abs(math_x_height)/4 RadicalDisplayStyleVerticalGap
³ \Umathradicalvgap T, T', S, S', SS, SS'	default_rule_thickness+abs(default_rule_thickness)/4 RadicalVerticalGap
² $\Umathradicaldegreebefore$	<not set> RadicalKernBeforeDegree
² \Umathradicaldegreeafter	<not set> RadicalKernAfterDegree
^{2,7} \Umathradicaldegreeraise	<not set> RadicalDegreeBottomRaisePercent
⁴ \Umathspaceafterscript	script_space SpaceAfterScript
\Umathstackdenomdown D, D'	denom1 StackBottomDisplayStyleShiftDown
\Umathstackdenomdown T, T', S, S', SS, SS'	denom2 StackBottomShiftDown
\Umathstacknumup	num1



D, D'	StackTopDisplayStyleShiftUp
\Umathstacknumup	num3
T, T', S, S', SS, SS'	StackTopShiftUp
\Umathstackvgap	7*default_rule_thickness
D, D'	StackDisplayStyleGapMin
\Umathstackvgap	3*default_rule_thickness
T, T', S, S', SS, SS'	StackGapMin
\Umathsubshiftdown	sub1 SubscriptShiftDown
\Umathsubshiftdrop	sub_drop SubscriptBaselineDropMin
⁸ \Umathsubsupshiftdown	– SubscriptShiftDownWithSuperscript
\Umathsubtopmax	abs(math_x_height*4)/5 SubscriptTopMax
\Umathsubsupvgap	4*default_rule_thickness SubSuperscriptGapMin
\Umathsupbottommin	abs(math_x_height/4) SuperscriptBottomMin
\Umathsupshiftdrop	sup_drop SuperscriptBaselineDropMax
\Umathsupshiftdown	sup1 SuperscriptShiftUp
D	
\Umathsupshiftdown	sup2 SuperscriptShiftUp
T, S, SS,	
\Umathsupshiftdown	sup3 SuperscriptShiftUpCramped
D', T', S', SS'	
\Umathsupsubbottommax	abs(math_x_height*4)/5 SuperscriptBottomMaxWithSubscript
\Umathunderbarkern	default_rule_thickness UnderbarExtraDescender
\Umathunderbarrule	default_rule_thickness UnderbarRuleThickness
\Umathunderbarvgap	3*default_rule_thickness UnderbarVerticalGap
⁵ \Umathconnectoroverlapmin	0 MinConnectorOverlap

Note 1: OpenType fonts set `\Umathlimitabovekern` and `\Umathlimitbelowkern` to zero and set `\Umathquad` to the font size of the used font, because these are not supported in the MATH table,

Note 2: Traditional tfm fonts do not set `\Umathradicalrule` because $\text{\TeX}82$ uses the height of the radical instead. When this parameter is indeed not set when \LuaTeX has to typeset a radical, a backward compatibility mode will kick in that assumes that an oldstyle \TeX font is used.



Also, they do not set `\Umathradicaldegreebefore`, `\Umathradicaldegreeafter`, and `\Umathradicaldegreeraise`. These are then automatically initialized to $5/18\text{quad}$, $-10/18\text{quad}$, and 60 .

Note 3: If tfm fonts are used, then the `\Umathradicalvgap` is not set until the first time LuaTeX has to typeset a formula because this needs parameters from both family 2 and family 3. This provides a partial backward compatibility with T_EX82, but that compatibility is only partial: once the `\Umathradicalvgap` is set, it will not be recalculated any more.

Note 4: When tfm fonts are used a similar situation arises with respect to `\Umathspaceafterscript`: it is not set until the first time LuaTeX has to typeset a formula. This provides some backward compatibility with T_EX82. But once the `\Umathspaceafterscript` is set, `\scriptspace` will never be looked at again.

Note 5: Traditional tfm fonts set `\Umathconnectoroverlapmin` to zero because T_EX82 always stacks extensibles without any overlap.

Note 6: The `\Umathoperatorsize` is only used in `\displaystyle`, and is only set in OpenType fonts. In tfm font mode, it is artificially set to one scaled point more than the initial attempt's size, so that always the 'first next' will be tried, just like in T_EX82.

Note 7: The `\Umathradicaldegreeraise` is a special case because it is the only parameter that is expressed in a percentage instead of a number of scaled points.

Note 8: `SubscriptShiftDownWithSuperscript` does not actually exist in the 'standard' OpenType math font Cambria, but it is useful enough to be added.

Note 9: `FractionDelimiterDisplayStyleSize` and `FractionDelimiterSize` do not actually exist in the 'standard' OpenType math font Cambria, but were useful enough to be added.

8.5 Math spacing

8.5.1 Setting inline surrounding space with `\mathsurround[skip]\mathsurround[skip]`

Inline math is surrounded by (optional) `\mathsurround` spacing but that is a fixed dimension. There is now an additional parameter `\mathsurroundskip`. When set to a non-zero value (or zero with some stretch or shrink) this parameter will replace `\mathsurround`. By using an additional parameter instead of changing the nature of `\mathsurround`, we can remain compatible. In the meantime a bit more control has been added via `\mathsurroundmode`. This directive can take 6 values with zero being the default behaviour.

```
\mathsurround 10pt
\mathsurroundskip20pt
```

MODE	X\$X\$X	X \$X\$ X	EFFECT
0	x x x x	x x	obey <code>\mathsurround</code> when <code>\mathsurroundskip</code> is 0pt
1	x xx	x x x	only add skip to the left
2	xx x	x x x	only add skip to the right
3	x x x x	x x	add skip to the left and right



4	x x x	x x x	ignore the skip setting, obey <code>\mathsurround</code>
5	xxx	x x x	disable all spacing around math
6	x x x x	x x	only apply <code>\mathsurroundskip</code> when also spacing
7	x x x	x x x	only apply <code>\mathsurroundskip</code> when no spacing

Anything more fancy, like checking the beginning or end of a paragraph (or edges of a box) would not be robust anyway. If you want that you can write a callback that runs over a list and analyzes a paragraph. Actually, in that case you could also inject glue (or set the properties of a math node) explicitly. So, these modes are in practice mostly useful for special purposes and experiments (they originate in a tracker item). Keep in mind that this glue is part of the math node and not always treated as normal glue: it travels with the begin and end math nodes. Also, method 6 and 7 will zero the skip related fields in a node when applicable in the first occasion that checks them (linebreaking or packaging).

8.5.2 Pairwise spacing and `\Umath...spacing` commands

Besides the parameters mentioned in the previous sections, there are also 64 new primitives to control the math spacing table (as explained in Chapter 18 of the `TEXbook`). The primitive names are a simple matter of combining two math atom types, but for completeness' sake, here is the whole list:

<code>\Umathordordspacing</code>	<code>\Umathrelordspacing</code>
<code>\Umathordopspacing</code>	<code>\Umathrelbinspacing</code>
<code>\Umathordbinspacing</code>	<code>\Umathrelrelspacing</code>
<code>\Umathordrelspacing</code>	<code>\Umathrelopenspacing</code>
<code>\Umathordopenspacing</code>	<code>\Umathrelclosespacing</code>
<code>\Umathordclosespacing</code>	<code>\Umathrelpunctspacing</code>
<code>\Umathordpunctspacing</code>	<code>\Umathrelinnerspacing</code>
<code>\Umathordinnerspacing</code>	<code>\Umathopenordspacing</code>
<code>\Umathopordspacing</code>	<code>\Umathopenopspacing</code>
<code>\Umathopopspacing</code>	<code>\Umathopenbinspacing</code>
<code>\Umathopbinspacing</code>	<code>\Umathopenrelspacing</code>
<code>\Umathoprelspacing</code>	<code>\Umathopenopenspacing</code>
<code>\Umathopopenspacing</code>	<code>\Umathopenclosespacing</code>
<code>\Umathopclosespacing</code>	<code>\Umathopenpunctspacing</code>
<code>\Umathoppunctspacing</code>	<code>\Umathopeninnerspacing</code>
<code>\Umathopinnerspacing</code>	<code>\Umathcloseordspacing</code>
<code>\Umathbinordspacing</code>	<code>\Umathcloseopspacing</code>
<code>\Umathbinopspacing</code>	<code>\Umathclosebinspacing</code>
<code>\Umathbinbinspacing</code>	<code>\Umathcloserelspacing</code>
<code>\Umathbinrelspacing</code>	<code>\Umathcloseopenspacing</code>
<code>\Umathbinopenspacing</code>	<code>\Umathcloseclosespacing</code>
<code>\Umathbinclosespacing</code>	<code>\Umathclosepunctspacing</code>
<code>\Umathbinpunctspacing</code>	<code>\Umathcloseinnerspacing</code>
<code>\Umathbininnerspacing</code>	<code>\Umathpunctordspacing</code>
<code>\Umathrelordspacing</code>	<code>\Umathpunctopspacing</code>



<code>\Umathpunctbinspacing</code>	<code>\Umathinneropspacing</code>
<code>\Umathpunctrelspacing</code>	<code>\Umathinnerbinspacing</code>
<code>\Umathpunctopenspacing</code>	<code>\Umathinnerrelspacing</code>
<code>\Umathpunctclosespacing</code>	<code>\Umathinneropenspacing</code>
<code>\Umathpunctpunctspacing</code>	<code>\Umathinnerclosespacing</code>
<code>\Umathpunctinnerspacing</code>	<code>\Umathinnerpunctspacing</code>
<code>\Umathinnerordspacing</code>	<code>\Umathinnerinnerspacing</code>

These parameters are of type `\muskip`, so setting a parameter can be done like this:

```
\Umathopordspacing\displaystyle=4mu plus 2mu
```

They are all initialized by `initex` to the values mentioned in the table in Chapter 18 of the `TEXbook`.

Note 1: For ease of use as well as for backward compatibility, `\thinmuskip`, `\medmuskip` and `\thickmuskip` are treated specially. In their case a pointer to the corresponding internal parameter is saved, not the actual `\muskip` value. This means that any later changes to one of these three parameters will be taken into account.

Note 2: Careful readers will realise that there are also primitives for the items marked * in the `TEXbook`. These will not actually be used as those combinations of atoms cannot actually happen, but it seemed better not to break orthogonality. They are initialized to zero.

8.5.3 Local `\frozen` settings with

Math is processed in two passes. The first pass is needed to intercept for instance `\over`, one of the few `TEX` commands that actually has a preceding argument. There are often lots of curly braces used in math and these can result in a nested run of the math sub engine. However, you need to be aware of the fact that some properties are kind of global to a formula and the last setting (for instance a family switch) wins. This also means that a change (or again, the last one) in math parameters affects the whole formula. In `LuaMetaTEX` we have changed this model a bit. One can argue that this introduces an incompatibility but it's hard to imagine a reason for setting the parameters at the end of a formula run and assume that they also influence what goes in front.

```
$
      \frozen\Umathsubshiftdown\textstyle 0pt x \Usubscript {-}
{\frozen\Umathsubshiftdown\textstyle 5pt x \Usubscript {0}
      x \Usubscript {5}}
{\frozen\Umathsubshiftdown\textstyle 15pt x \Usubscript {0}
      x \Usubscript {15}}
{\frozen\Umathsubshiftdown\textstyle 20pt x \Usubscript {0}
      x \Usubscript {20}}
      \frozen\Umathsubshiftdown\textstyle 10pt x \Usubscript {0}
      x \Usubscript {10}
      x \Usubscript {0}
$
```



The `\frozen` prefix does the magic: it injects information in the math list about the set parameter. In LuaTeX 1.10+ the last setting, the 10pt drop wins, but in LuaMetaTeX you will see each local setting taking effect. The implementation uses a new node type, parameters nodes, so you might encounter these in an unprocessed math list. The result looks as follows:

$$x_{-x_0x_5x_0x} \quad x_0x \quad x_0x \quad x$$

15 20 10 0

8.5.4 Checking a state with `\ifmathparameter`

When you adapt math parameters it might make sense to see if they are set at all. When a parameter is unset its value has the maximum dimension value and you might for instance mistakenly multiply that value to open up things a bit, which gives unexpected side effects. For that reason there is a convenient checker: `\ifmathparameter`. This test primitive behaves like an `\ifcase`, with:

VALUE	MEANING
0	the parameter value is zero
1	the parameter is set
2	the parameter is unset

8.5.5 Skips around display math and `\mathdisplayskipmode`

The injection of `\abovedisplayskip` and `\belowdisplayskip` is not symmetrical. An above one is always inserted, also when zero, but the below is only inserted when larger than zero. Especially the latter makes it sometimes hard to fully control spacing. Therefore LuaTeX comes with a new directive: `\mathdisplayskipmode`. The following values apply:

VALUE	MEANING
0	normal TeX behaviour
1	always (same as 0)
2	only when not zero
3	never, not even when not zero

8.5.6 Nolimit correction with `\mathnolimitsmode`

There are two extra math parameters `\Umathnolimitsupfactor` and `\Umathnolimitssubfactor` that were added to provide some control over how limits are spaced (for example the position of super and subscripts after integral operators). They relate to an extra parameter `\mathnolimitsmode`. The half corrections are what happens when scripts are placed above and below. The problem with italic corrections is that officially that correction italic is used for above/below placement while advanced kerns are used for placement at the right end. The question is: how often is this implemented, and if so, do the kerns assume correction too. Anyway, with this parameter one can control it.



	\int_1^0	\int_1^0	\int_1^0	\int_1^0	\int_1^0	\int_1^0
mode	0	1	2	3	4	8000
superscript	0	font	0	0	+ic/2	0
subscript	-ic	font	0	-ic/2	-ic/2	8000ic/1000

When the mode is set to one, the math parameters are used. This way a macro package writer can decide what looks best. Given the current state of fonts in ConTeXt we currently use mode 1 with factor 0 for the superscript and 750 for the subscripts. Positive values are used for both parameters but the subscript shifts to the left. A `\mathnolimitsmode` larger than 15 is considered to be a factor for the subscript correction. This feature can be handy when experimenting.

8.5.7 Controlling math italic mess with `\mathitalicsmode`

The `\mathitalicsmode` parameter can be set to 1 to force italic correction before noads that represent some more complex structure (read: everything that is not an ord, bin, rel, open, close, punct or inner). We show a Cambria example.

```
\mathitalicsmode = 0  $\mathit{T}^1$   $\mathit{T}$   $\mathit{T}+1$   $\mathit{T}_{\frac{1}{2}}$   $\mathit{T}\sqrt{1}$ 
\mathitalicsmode = 1  $\mathit{T}^1$   $\mathit{T}$   $\mathit{T}+1$   $\mathit{T}_{\frac{1}{2}}$   $\mathit{T}\sqrt{1}$ 
```

This kind of parameters relate to the fact that italic correction in OpenType math is bound to fuzzy rules. So, control is the solution.

8.5.8 Influencing script kerning with `\mathscriptboxmode`

If you want to typeset text in math macro packages often provide something `\text` which obeys the script sizes. As the definition can be anything there is a good chance that the kerning doesn't come out well when used in a script. Given that the first glyph ends up in an `\hbox` we have some control over this. And, as a bonus we also added control over the normal sublist kerning. The `\mathscriptboxmode` parameter defaults to 1.

VALUE	MEANING
0	forget about kerning
1	kern math sub lists with a valid glyph
2	also kern math sub boxes that have a valid glyph
3	only kern math sub boxes with a boundary node present

Here we show some examples. Of course this doesn't solve all our problems, if only because some fonts have characters with bounding boxes that compensate for italics, while other fonts can lack kerns.

	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$
	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$
	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$
mode 0		mode 1	mode 1	mode 2	mode 3
modern	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$
lucidaot	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$
pagella	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$	$\mathit{T}_{\text{fluff}}$



cambria T_{fluff} T_{fluff} T_{fluff} T_{fluff} T_{fluff}
 dejavu T_{fluff} T_{fluff} T_{fluff} T_{fluff} T_{fluff}

Kerning between a character subscript is controlled by `\mathscriptcharmode` which also defaults to 1.

Here is another example. Internally we tag kerns as italic kerns or font kerns where font kerns result from the staircase kern tables. In 2018 fonts like Latin Modern and Pagella rely on cheats with the boundingbox, Cambria uses staircase kerns and Lucida a mixture. Depending on how fonts evolve we might add some more control over what one can turn on and off.

normal	modern	T_f	γ_e	γ_{ee}	T_{fluff}
	pagella	T_f	γ_e	γ_{ee}	T_{fluff}
	cambria	T_f	γ_e	γ_{ee}	T_{fluff}
	lucidaot	T_f	γ_e	γ_{ee}	T_{fluff}
bold	modern	T_f	γ_e	γ_{ee}	T_{fluff}
	pagella	T_f	γ_e	γ_{ee}	T_{fluff}
	cambria	T_f	γ_e	γ_{ee}	T_{fluff}
	lucidaot	T_f	γ_e	γ_{ee}	T_{fluff}

8.5.9 Forcing fixed scripts with `\mathscriptsmode`

We have three parameters that are used for this fixed anchoring:

PARAMETER	REGISTER
d	<code>\Umathsubshiftdown</code>
u	<code>\Umathsupshiftup</code>
s	<code>\Umathsubsupshiftdown</code>

When we set `\mathscriptsmode` to a value other than zero these are used for calculating fixed positions. This is something that is needed for instance for chemistry. You can manipulate the mentioned variables to achieve different effects.

MODE	DOWN	UP	EXAMPLE
0	dynamic	dynamic	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$
1	d	u	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$
2	s	u	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$
3	s	$u + s - d$	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$
4	$d + (s - d)/2$	$u + (s - d)/2$	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$
5	d	$u + s - d$	$\text{CH}_2 + \text{CH}_2^+ + \text{CH}_2^2$

The value of this parameter obeys grouping but applies to the whole current formula.



8.5.10 Penalties: `\mathpenaltiesmode`

Only in inline math penalties will be added in a math list. You can force penalties (also in display math) by setting:

```
\mathpenaltiesmode = 1
```

This primitive is not really needed in Lua \TeX because you can use the callback `mlist_to_hlist` to force penalties by just calling the regular routine with forced penalties. However, as part of opening up and control this primitive makes sense. As a bonus we also provide two extra penalties:

```
\prebinoppenalty = -100 % example value
```

```
\prerelpenalty = 900 % example value
```

They default to infinite which signals that they don't need to be inserted. When set they are injected before a binop or rel noad. This is an experimental feature.

8.5.11 Equation spacing: `\matheqnogapstep`

By default \TeX will add one quad between the equation and the number. This is hard coded. A new primitive can control this:

```
\matheqnogapstep = 1000
```

Because a math quad from the math text font is used instead of a dimension, we use a step to control the size. A value of zero will suppress the gap. The step is divided by 1000 which is the usual way to mimick floating point factors in \TeX .

8.6 Math constructs

8.6.1 Unscaled fences and `\mathdelimitersmode`

The `\mathdelimitersmode` primitive is experimental and deals with the following (potential) problems. Three bits can be set. The first bit prevents an unwanted shift when the fence symbol is not scaled (a cambria side effect). The second bit forces italic correction between a preceding character ordinal and the fenced subformula, while the third bit turns that subformula into an ordinary so that the same spacing applies as with unfenced variants. Here we show Cambria (with `\mathitalicsmode` enabled).

<code>\mathdelimitersmode = 0</code>		
<code>\mathdelimitersmode = 1</code>		
<code>\mathdelimitersmode = 2</code>		
<code>\mathdelimitersmode = 3</code>		
<code>\mathdelimitersmode = 4</code>		
<code>\mathdelimitersmode = 5</code>		
<code>\mathdelimitersmode = 6</code>		
<code>\mathdelimitersmode = 7</code>		



So, when set to 7 fenced subformulas with unscaled delimiters come out the same as unfenced ones. This can be handy for cases where one is forced to use `\left` and `\right` always because of unpredictable content. As said, it's an experimental feature (which somehow fits in the exceptional way fences are dealt with in the engine). The full list of flags is given in the next table:

VALUE	MEANING
"01	don't apply the usual shift
"02	apply italic correction when possible
"04	force an ordinary subformula
"08	no shift when a base character
"10	only shift when an extensible

The effect can depend on the font (and for Cambria one can use for instance "16).

Sometimes you might want to act upon the size of a delimiter, something that is not really possible because of the fact that they are calculated *after* most has been typeset already. For this we have two keyword: `phantom` and `void`. In both cases the symbol is replaced by an empty rule, in the first case all three dimensions are preserved in the last case only the height and depth.

```
\startformula
  x\mathlimop{\Uvextensible          \Udelimiter 5 0 "222B}_1^2 x
\stopformula
\vskip-9ex
\startformula \red
  x\mathlimop{\Uvextensible phantom \Udelimiter 5 0 "222B}_1^2 x
\stopformula
\vskip-9ex
\startformula \blue
  x\mathlimop{\Uvextensible void     \Udelimiter 5 0 "222B}_1^2 x
\stopformula
                                     x x
```

In typeset form this looks like: x x

8.6.2 Accent handling with `\Umathaccent`

Lua_T_E_X supports both top accents and bottom accents in math mode, and math accents stretch automatically (if this is supported by the font the accent comes from, of course). Bottom and combined accents as well as fixed-width math accents are controlled by optional keywords following `\Umathaccent`.

The keyword `bottom` after `\Umathaccent` signals that a bottom accent is needed, and the keyword `both` signals that both a top and a bottom accent are needed (in this case two accents need to be specified, of course).

Then the set of three integers defining the accent is read. This set of integers can be prefixed by the fixed keyword to indicate that a non-stretching variant is requested (in case of both accents, this step is repeated).

A simple example:



```
\Umathaccent both fixed 0 0 "20D7 fixed 0 0 "20D7 {example}
```

If a math top accent has to be placed and the accentee is a character and has a non-zero `top_accent` value, then this value will be used to place the accent instead of the `\skewchar` kern used by T_EX82.

The `top_accent` value represents a vertical line somewhere in the accentee. The accent will be shifted horizontally such that its own `top_accent` line coincides with the one from the accentee. If the `top_accent` value of the accent is zero, then half the width of the accent followed by its italic correction is used instead.

The vertical placement of a top accent depends on the `x_height` of the font of the accentee (as explained in the T_EXbook), but if a value turns out to be zero and the font had a `MathConstants` table, then `AccentBaseHeight` is used instead.

The vertical placement of a bottom accent is straight below the accentee, no correction takes place.

Possible locations are `top`, `bottom`, `both` and `center`. When no location is given `top` is assumed. An additional parameter `fraction` can be specified followed by a number; a value of for instance 1200 means that the criterium is 1.2 times the width of the nucleus. The `fraction` only applies to the stepwise selected shapes and is mostly meant for the `overlay` location. It also works for the other locations but then it concerns the width.

8.6.3 Building radicals with `\Uradical` and `\Uroot`

The new primitive `\Uroot` allows the construction of a radical noad including a degree field. Its syntax is an extension of `\Uradical`:

```
\Uradical <fam integer> <char integer> <radicand>  
\Uroot    <fam integer> <char integer> <degree> <radicand>
```

The placement of the degree is controlled by the math parameters `\Umathradicaldegreebefore`, `\Umathradicaldegreeafter`, and `\Umathradicaldegreeraise`. The degree will be typeset in `\scriptscriptstyle`.

8.6.4 Super- and subscripts

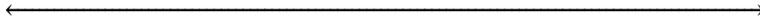
The character fields in a Lua-loaded OpenType math font can have a ‘`mathkern`’ table. The format of this table is the same as the ‘`mathkern`’ table that is returned by the `fontloader` library, except that all height and kern values have to be specified in actual scaled points.

When a super- or subscript has to be placed next to a math item, LuaT_EX checks whether the super- or subscript and the nucleus are both simple character items. If they are, and if the fonts of both character items are OpenType fonts (as opposed to legacy T_EX fonts), then LuaT_EX will use the OpenType math algorithm for deciding on the horizontal placement of the super- or subscript.

This works as follows:

- ▶ The vertical position of the script is calculated.





Here you can also pass options, like:

```
\Uhexensible width 1pt middle 0 "2194$
```

This gives:



LuaT_EX internally uses a structure that supports OpenType ‘MathVariants’ as well as tfm ‘extensible recipes’. In most cases where font metrics are involved we have a different code path for traditional fonts and OpenType fonts.

8.6.6 Fractions and the new `\Uskewed` and `\Uskewedwithdelims`

The `\abovewithdelims` command accepts a keyword `exact`. When issued the extra space relative to the rule thickness is not added. One can of course use the `\Umathfraction.gap` commands to influence the spacing. Also the rule is still positioned around the math axis.

```
$$ { {a} \abovewithdelims() exact 4pt {b} }$$
```

The math parameter table contains some parameters that specify a horizontal and vertical gap for skewed fractions. Of course some guessing is needed in order to implement something that uses them. And so we now provide a primitive similar to the other fraction related ones but with a few options so that one can influence the rendering. Of course a user can also mess around a bit with the parameters `\Umathskewedfractionhgap` and `\Umathskewedfractionvgap`.

The syntax used here is:

```
{ {1} \Uskewed / <options> {2} }
{ {1} \Uskewedwithdelims / () <options> {2} }
```

where the options can be `noaxis` and `exact`. By default we add half the axis to the shifts and by default we zero the width of the middle character. For Latin Modern the result looks as follows:

	$x + \frac{a}{b} + x$	$x + \frac{1}{2} + x$	$x + \left(\frac{a}{b}\right) + x$	$x + \left(\frac{1}{2}\right) + x$
<code>exact</code>	$x + \frac{a}{\text{exact}b} + x$	$x + \frac{1}{\text{exact}2} + x$	$x + \left(\frac{a}{\text{exact}b}\right) + x$	$x + \left(\frac{1}{\text{exact}2}\right) + x$
<code>noaxis</code>	$x + \frac{a}{\text{noaxis}b} + x$	$x + \frac{1}{\text{noaxis}2} + x$	$x + \left(\frac{a}{\text{noaxis}b}\right) + x$	$x + \left(\frac{1}{\text{noaxis}2}\right) + x$
<code>exact noaxis</code>	$x + \frac{a}{\text{exactnoaxis}b} + x$	$x + \frac{1}{\text{exactnoaxis}2} + x$	$x + \left(\frac{a}{\text{exactnoaxis}b}\right) + x$	$x + \left(\frac{1}{\text{exactnoaxis}2}\right) + x$

The `\over` and related primitives have the form:

```
{{top}\over{bottom}}
```

For convenience, which also avoids some of the trickery that makes this ‘looking back’ possible, the LuaMetaT_EX also provides this variant:

```
\Uover{top}{bottom}
```

The optional arguments are also supported but we have one extra option: `style`. The style is



applied to the numerator and denominator.

```
\Uover style \scriptstyle {top} {bottom}
```

The complete list of these commands is: `\Uabove`, `\Uatop`, `\Uover`, `\Uabovewithdelims`, `\Uatopwithdelims`, `\Uoverwithdelims`, `\UUskewed`, `\UUskewedwithdelims`. As with other extensions we use a leading U and because we already had extra skew related primitives we end up with a UU there. This obscurity is not that big an issue because normally such primitives are wrapped in a macro. Here are a few examples:

```


$$\Uover {1234} {5678} \quad$$


$$\Uover {\textstyle 1234} {\textstyle 5678} \quad$$


$$\Uover {\scriptstyle 1234} {\scriptstyle 5678} \quad$$


$$\Uover {\scriptscriptstyle 1234} {\scriptscriptstyle 5678} \quad$$


```

```


$$\Uover {1234} {5678} \quad$$


$$\Uover style \textstyle {1234} {5678} \quad$$


$$\Uover style \scriptstyle {1234} {5678} \quad$$


$$\Uover style \scriptscriptstyle {1234} {5678} \quad$$


```

These render as: $\frac{1234}{5678}$ $\frac{1234}{5678}$ $\frac{1234}{5678}$ $\frac{1234}{5678}$

$\frac{1234}{5678}$ $\frac{1234}{5678}$ $\frac{1234}{5678}$ $\frac{1234}{5678}$

8.6.7 Math styles: `\Ustyle`

This primitive accepts a style identifier:

```
\Ustyle \displaystyle
```

This in itself is not spectacular because it is equivalent to

```
\displaystyle
```

Both commands inject a style node and change the current style. However, as in other places where LuaMetaTeX expects a style you can also pass a number in the range zero upto seven (like the ones reported by the primitive `\mathstyle`). So, the next few lines give identical results:

Like: 0_7 0_7 0_7 . Values outside the valid range are ignored.

There is an extra option `norule` that can be used to suppress the rule while keeping the spacing compatible.

8.6.8 Delimiters: `\Uleft`, `\Umiddle` and `\Uright`

Normally you will force delimiters to certain sizes by putting an empty box or rule next to it. The resulting delimiter will either be a character from the stepwise size range or an extensible. The latter can be quite differently positioned than the characters as it depends on the fit as well as the fact whether the used characters in the font have depth or height. Commands like (plain

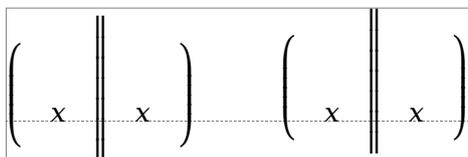


TeXs) `\big` need to use this feature. In LuaTeX we provide a bit more control by three variants that support optional parameters `height`, `depth` and `axis`. The following example uses this:

```

\Uleft   height 30pt depth 10pt   \Udelimiter "0 "0 "000028
\quad x\quad
\Umiddle height 40pt depth 15pt   \Udelimiter "0 "0 "002016
\quad x\quad
\Uright  height 30pt depth 10pt   \Udelimiter "0 "0 "000029
\quad \quad \quad
\Uleft   height 30pt depth 10pt axis \Udelimiter "0 "0 "000028
\quad x\quad
\Umiddle height 40pt depth 15pt axis \Udelimiter "0 "0 "002016
\quad x\quad
\Uright  height 30pt depth 10pt axis \Udelimiter "0 "0 "000029

```



The keyword `exact` can be used as directive that the real dimensions should be applied when the criteria can't be met which can happen when we're still stepping through the successively larger variants. When no dimensions are given the `noaxis` command can be used to prevent shifting over the axis.

You can influence the final class with the keyword `class` which will influence the spacing. The numbers are the same as for character classes.

8.6.9 Accents: `\mathlimitsmode`

When you use `\limits` or `\nolimits` without scripts spacing might get messed up. This can be prevented by setting `\mathlimitsmode` to a non-zero value.

8.7 Extracting values

8.7.1 Codes and using `\Umathcode`, `\Umathcharclass`, `\Umathcharfam` and `\Umathcharslot`

You can extract the components of a math character. Say that we have defined:

```
\Umathcode 1 2 3 4
```

then

```
[\Umathcharclass1] [\Umathcharfam1] [\Umathcharslot1]
```

will return:



[2] [3] [4]

These commands are provided as convenience. Before they come available you could do the following:

```
\def\Umathcharclass{\numexpr
  \directlua{tex.print(tex.getmathcode(token.scan_int())[1])}
\relax}
\def\Umathcharfam{\numexpr
  \directlua{tex.print(tex.getmathcode(token.scan_int())[2])}
\relax}
\def\Umathcharslot{\numexpr
  \directlua{tex.print(tex.getmathcode(token.scan_int())[3])}
\relax}
```

8.7.2 Last lines and `\predisplaygapfactor`

There is a new primitive to control the overshoot in the calculation of the previous line in mid-paragraph display math. The default value is 2 times the em width of the current font:

```
\predisplaygapfactor=2000
```

If you want to have the length of the last line independent of math i.e. you don't want to revert to a hack where you insert a fake display math formula in order to get the length of the last line, the following will often work too:

```
\def\lastlinelength{\dimexpr
  \directlua {tex.sprint (
    (nodes.dimensions(node.tail(tex.lists.page_head).list))
  )}sp
\relax}
```

8.8 Math mode

8.8.1 Verbose versions of single-character math commands like `\Usuperscript` and `\Usubscript`

Lua_T_EX defines six new primitives that have the same function as `^`, `_`, `$`, and `$$`:

PRIMITIVE	EXPLANATION
<code>\Usuperscript</code>	duplicates the functionality of <code>^</code>
<code>\Usubscript</code>	duplicates the functionality of <code>_</code>
<code>\Ustartmath</code>	duplicates the functionality of <code>\$</code> , when used in non-math mode.
<code>\Ustopmath</code>	duplicates the functionality of <code>\$</code> , when used in inline math mode.



`\Ustartdisplaymath` duplicates the functionality of `$$`, when used in non-math mode.
`\Ustopdisplaymath` duplicates the functionality of `$$`, when used in display math mode.

The `\Ustopmath` and `\Ustopdisplaymath` primitives check if the current math mode is the correct one (inline vs. displayed), but you can freely intermix the four `mathon/mathoff` commands with explicit dollar sign(s).

8.8.2 Script commands `\Unosuperscript` and `\Unosubscript`

These two commands result in super- and subscripts but with the current style (at the time of rendering). So,

```
$
  x\Unosuperscript {1}\Unosubscript {2} =
  x\Unosuperscript{1}\Unosubscript{2} =
  x\Unosuperscript {1}\Unosubscript{2} =
  x\Unosuperscript{1}\Unosubscript {2}
$
```

results in $x_2^1 = x_2^1 = x_2^1 = x_2^1$.

8.8.3 Allowed math commands in non-math modes

The commands `\mathchar`, and `\Umathchar` and control sequences that are the result of `\mathchardef` or `\Umathchardef` are also acceptable in the horizontal and vertical modes. In those cases, the `\textfont` from the requested math family is used.

8.9 Goodies

8.9.1 Flattening: `\mathflattenmode`

The \TeX math engine collapses ord noads without sub- and superscripts and a character as nucleus, which has the side effect that in OpenType mode italic corrections are applied (given that they are enabled).

```
\switchtobodyfont[modern]
$V \mathbin{\mathbin{v}} V$\par
$V \mathord{\mathord{v}} V$\par
```

This renders as:

VvV
 VvV

When we set `\mathflattenmode` to 31 we get:



$V v V$

$V v V$

When you see no difference, then the font probably has the proper character dimensions and no italic correction is needed. For Latin Modern (at least till 2018) there was a visual difference. In that respect this parameter is not always needed unless of course you want efficient math lists anyway.

You can influence flattening by adding the appropriate number to the value of the mode parameter. The default value is 1.

MODE	CLASS
1	ord
2	bin
4	rel
8	punct
16	inner

8.9.2 Less Tracing

Because there are quite some math related parameters and values, it is possible to limit tracing. Only when `tracingassigns` and/or `tracingrestores` are set to 2 or more they will be traced.

8.10 Experiments

There are a couple of experimental features. They will stay but details might change, for instance more control over spacing. We just show some examples and let your imagination work it out. First we have prescripts:

8.10.1 Prescripts with `\Usuperprescript` and `\Usubprescript`

```
\hbox{$
  {\tf X}^1_2^^3__4 \quad
  {\tf X}^1 ^^3 \quad
  {\tf X} _1 __4 \quad
  {\tf X} ^^3 \quad
  {\tf X} __4 \quad
  {\tf X}^^3 __4
$}
```

The question is: are these double super and subscript triggers the way to go? Anyway, you need to have them either being active (which in `ConTEXt` then boils down to them being other characters), or say `\supmarkmode = 1` to disable the normal multiple `^` treatment (a value larger than 1 will also disable that in text mode).

${}^3x_4^1$ ${}^3X^1$ ${}_4X_1$ 3X ${}_4X$ 3X_4





9 Nodes

9.1 Lua node representation

\TeX 's nodes are represented in Lua as userdata objects with a variable set of fields or by a numeric identifier when requested. When you print a node userdata object you will see these numbers. In the following syntax tables the type of such a userdata object is represented as `<node>`.

The return values of `node.types` are: `hlist` (0), `vlist` (1), `rule` (2), `insert` (3), `mark` (4), `adjust` (5), `boundary` (6), `disc` (7), `whatsit` (8), `par` (9), `dir` (10), `math` (11), `glue` (12), `kern` (13), `penalty` (14), `style` (15), `choice` (16), `parameter` (17), `noad` (18), `radical` (19), `fraction` (20), `accent` (21), `fence` (22), `math_char` (23), `math_text_char` (24), `sub_box` (25), `sub_mlist` (26), `delimiter` (27), `glyph` (28), `unset` (29), `attribute_list` (32), `attribute` (33), `glue_spec` (34), `temp` (35) and `split` (36)

In $\varepsilon\text{-}\TeX$ the `\lastnodetype` primitive has been introduced. With this primitive the valid range of numbers is still $[-1, 15]$ and `glyph` nodes (formerly known as `char` nodes) have number 0. That way macro packages can use the same symbolic names as in traditional $\varepsilon\text{-}\TeX$. But you need to keep in mind that these $\varepsilon\text{-}\TeX$ node numbers are different from the real internal ones. When you set `\internalcodesmode` to a non-zero value, the internal codes will be used in the $\varepsilon\text{-}\TeX$ introspection commands `\lastnodetype` and `\currentiftyp`.

You can ask for a list of fields with `node.fields` and for valid subtypes with `node.subtypes`. The `node.values` function reports some used values. Valid arguments are `glue`, `style` and `math`. Keep in mind that the setters normally expect a number, but this helper gives you a list of what numbers matter. For practical reason the `pagestate` values are also reported with this helper, but they are backend specific.

The return values of `node.values("glue")` are: `normal` (0), `fi` (1), `fil` (2), `fill` (3) and `filll` (4)

The return values of `node.values("style")` are: `display` (0), `crampeddisplay` (1), `text` (2), `crampedtext` (3), `script` (4), `crampedscript` (5), `scriptscript` (6) and `crampedscriptscript` (7)

The return values of `node.values("math")` are: `quad` (0), `axis` (1), `accentbaseheight` (2), `spacingmode` (3), `operatorsize` (4), `overbarkern` (5), `overbarrule` (6), `overbarvgap` (7), `underbarkern` (8), `underbarrule` (9), `underbarvgap` (10), `radicalkern` (11), `radicalrule` (12), `radicalvgap` (13), `radicaldegreebefore` (14), `radicaldegreeafter` (15), `radicaldegreerise` (16), `stackvgap` (17), `stacknumup` (18), `stackdenomdown` (19), `fractionrule` (20), `fractionnumvgap` (21), `fractionnumup` (22), `fractiondenomvgap` (23), `fractiondenomdown` (24), `fractiondelimiter` (25), `skewedfractionhgap` (26), `skewedfractionvgap` (27), `limitabovevgap` (28), `limitabovebgap` (29), `limitabovekern` (30), `limitbelowvgap` (31), `limitbelowbgap` (32), `limitbelowkern` (33), `nolimitsubfactor` (34), `nolimitsupfactor` (35), `underdelimitervgap` (36), `underdelimiterbgap` (37), `overdelimitervgap` (38), `overdelimiterbgap` (39), `subshiftdrop` (40),



supshiftdrop (41), subshiftdown (42), subsupshiftdown (43), subtopmax (44), supshiftdown (45), supbottommin (46), supsubbottommax (47), subsupvgap (48), spacebeforescript (49), spaceafterscript (50), connectoroverlapmin (51), ordordspacing (52), ordopspacing (53), ordbinspacing (54), ordrelspacing (55), ordopspacing (56), ordclosespacing (57), ordpunctspacing (58), ordinnerspacing (59), opordspacing (60), opopspacing (61), opbinspacing (62), oprelspacing (63), opopspacing (64), opclosespacing (65), oppunctspacing (66), opinnerspacing (67), binordspacing (68), binopspacing (69), binbinspacing (70), binrelspacing (71), binopspacing (72), binclosespacing (73), binpunctspacing (74), bininnerspacing (75), relordspacing (76), relopspacing (77), relbinspacing (78), relrelspacing (79), relopenspacing (80), relclosespacing (81), relpunctspacing (82), relinnerspacing (83), openordspacing (84), openopspacing (85), openbinspacing (86), openrelspacing (87), openopspacing (88), openclosespacing (89), openpunctspacing (90), openinnerspacing (91), closeordspacing (92), closeopspacing (93), closebinspacing (94), closerelspacing (95), closeopspacing (96), closeclosespacing (97), closepunctspacing (98), closeinnerspacing (99), punctordspacing (100), punctopspacing (101), punctbinspacing (102), punctrelspacing (103), punctopspacing (104), punctclosespacing (105), punctpunctspacing (106), punctinnerspacing (107), innerordspacing (108), inneropspacing (109), innerbinspacing (110), innerrelspacing (111), inneropspacing (112), innerclosespacing (113), innerpunctspacing (114), innerinnerspacing (115), overlinevariant (116), underlinevariant (117), overdelimitervariant (118), underdelimitervariant (119), delimiterovervariant (120), delimiterundervariant (121), hextensiblevariant (122), vextensiblevariant (123), fractionvariant (124), radicalvariant (125), accentvariant (126), degreevariant (127), topaccentvariant (128), botaccentvariant (129), overlayaccentvariant (130), numeratorvariant (131), denominatorvariant (132), superscriptvariant (133), subscriptvariant (134) and stackvariant (135)

The return values of `node.values("pagestate")` are:

9.2 Main text nodes

These are the nodes that comprise actual typesetting commands. A few fields are present in all nodes regardless of their type, these are:

FIELD	TYPE	EXPLANATION
<code>next</code>	node	the next node in a list, or nil
<code>id</code>	number	the node's type (id) number
<code>subtype</code>	number	the node subtype identifier

The subtype is sometimes just a dummy entry because not all nodes actually use the subtype, but this way you can be sure that all nodes accept it as a valid field name, and that is often handy in node list traversal. In the following tables `next` and `id` are not explicitly mentioned.

Besides these three fields, almost all nodes also have an `attr` field, and there is also a field called `prev`. That last field is always present, but only initialized on explicit request: when the function `node.slide` is called, it will set up the `prev` fields to be a backwards pointer in the argument node list. By now most of \TeX 's node processing makes sure that the `prev` nodes are valid but there can be exceptions, especially when the internal magic uses a leading temp nodes



to temporarily store a state.

The LuaMetaTeX engine provides a lot of freedom and it is up to the user to make sure that the node lists remain sane. There are some safeguards but there can be cases where the engine just quits out of frustration. And, of course you can make the engine crash.

9.2.1 hlist and vlist nodes

These lists share fields and subtypes although some subtypes can only occur in horizontal lists while others are unique for vertical lists. The possible fields are `attr`, `depth`, `direction`, `doffset`, `glue_order`, `glue_set`, `glue_sign`, `height`, `hoffset`, `list`, `orientation`, `shift`, `state`, `width`, `woffset`, `xoffset` and `yoffset`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	accent, alignment, box, cell, container, degree, denominator, equation, equationnumber, fraction, hdelimiter, hextensible, indent, line, math, mathchar, modifier, nucleus, numerator, over, overdelimit, radical, scripts, sub, sup, under, underdelimit, unknown, vdelimit and vextensible
<code>attr</code>	node	list of attributes
<code>width</code>	number	the width of the box
<code>height</code>	number	the height of the box
<code>depth</code>	number	the depth of the box
<code>direction</code>	number	the direction of this box, see 9.2.15
<code>shift</code>	number	a displacement perpendicular to the character (hlist) or line (vlist) progression direction
<code>glue_order</code>	number	a number in the range [0, 4], indicating the glue order
<code>glue_set</code>	number	the calculated glue ratio
<code>glue_sign</code>	number	0 = normal, 1 = stretching, 2 = shrinking
<code>list</code>	node	the first node of the body of this list

The `orientation`, `woffset`, `hoffset`, `doffset`, `xoffset` and `yoffset` fields are special. They can be used to make the backend rotate and shift boxes which can be handy in for instance vertical typesetting. Because they relate to (and depend on the) the backend they are not discussed here (yet).

A warning: never assign a node list to the `list` field unless you are sure its internal link structure is correct, otherwise an error may result.

Note: the field name `head` and `list` are both valid. Sometimes it makes more sense to refer to a list by `head`, sometimes `list` makes more sense.

9.2.2 rule nodes

Contrary to traditional TeX, LuaTeX has more `\rule` subtypes because we also use rules to store reusable objects and images. User nodes are invisible and can be intercepted by a callback. The supported fields are `attr`, `data`, `depth`, `height`, `left`, `right`, `width`, `xoffset` and `yoffset`.



FIELD	TYPE	EXPLANATION
subtype	number	box, empty, fraction, image, normal, outline, over, radical, under and user
attr	node	list of attributes
width	number	the width of the rule where the special value -1073741824 is used for 'running' glue dimensions
height	number	the height of the rule (can be negative)
depth	number	the depth of the rule (can be negative)
left	number	shift at the left end (also subtracted from width)
right	number	(subtracted from width)
dir	string	the direction of this rule, see 9.2.15
index	number	an optional index that can be referred to
transform	number	an private variable (also used to specify outline width)

The left and type right keys are somewhat special (and experimental). When rules are auto adapting to the surrounding box width you can enforce a shift to the right by setting left. The value is also subtracted from the width which can be a value set by the engine itself and is not entirely under user control. The right is also subtracted from the width. It all happens in the backend so these are not affecting the calculations in the frontend (actually the auto settings also happen in the backend). For a vertical rule left affects the height and right affects the depth. There is no matching interface at the $\text{T}_{\text{E}}\text{X}$ end (although we can have more keywords for rules it would complicate matters and introduce a speed penalty.) However, you can just construct a rule node with Lua and write it to the $\text{T}_{\text{E}}\text{X}$ input. The outline subtype is just a convenient variant and the transform field specifies the width of the outline.

The xoffset and yoffset fields are special. They can be used to shift rules. Because they relate to (and depend on the) the backend they are not discussed here (yet).

9.2.3 insert nodes

This node relates to the `\insert` primitive and support the fields: attr, cost, depth, height, list and spec.

FIELD	TYPE	EXPLANATION
subtype	number	the insertion class
attr	node	list of attributes
cost	number	the penalty associated with this insert
height	number	height of the insert
depth	number	depth of the insert
list	node	the first node of the body of this insert

There is a set of extra fields that concern the associated glue: width, stretch, stretch_order, shrink and shrink_order. These are all numbers.

A warning: never assign a node list to the head field unless you are sure its internal link structure is correct, otherwise an error may result. You can use list instead (often in functions you want to use local variable with similar names and both names are equally sensible).



9.2.4 mark nodes

This one relates to the `\mark` primitive and only has a few fields: `attr`, `class` and `mark`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	unused
<code>attr</code>	node	list of attributes
<code>class</code>	number	the mark class
<code>mark</code>	table	a table representing a token list

9.2.5 adjust nodes

This node comes from `\vadjust` primitive and has fields: `attr` and `list`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	normal and pre
<code>attr</code>	node	list of attributes
<code>list</code>	node	adjusted material

A warning: never assign a node list to the head field unless you are sure its internal link structure is correct, otherwise an error may be the result.

9.2.6 disc nodes

The `\discretionary` and `\-`, the `-` character but also the hyphenation mechanism produces these nodes. The available fields are: `attr`, `options`, `penalty`, `post`, `pre` and `replace`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	automatic, discretionary, explicit and regular
<code>attr</code>	node	list of attributes
<code>pre</code>	node	pointer to the pre-break text
<code>post</code>	node	pointer to the post-break text
<code>replace</code>	node	pointer to the no-break text
<code>penalty</code>	number	the penalty associated with the break, normally <code>\hyphenpenalty</code> or <code>\exhyphenpenalty</code>

The subtype numbers 4 and 5 belong to the ‘of-ice’ explanation given elsewhere. These disc nodes are kind of special as at some point they also keep information about breakpoints and nested ligatures.

The `pre`, `post` and `replace` fields at the Lua end are in fact indirectly accessed and have a `prev` pointer that is not `nil`. This means that when you mess around with the head of these (three) lists, you also need to reassign them because that will restore the proper `prev` pointer, so:

```
pre = d.pre
-- change the list starting with pre
d.pre = pre
```



Otherwise you can end up with an invalid internal perception of reality and LuaMetaTeX might even decide to crash on you. It also means that running forward over for instance `pre` is ok but backward you need to stop at `pre`. And you definitely must not mess with the node that `prev` points to, if only because it is not really a node but part of the disc data structure (so freeing it again might crash LuaMetaTeX).

9.2.7 math nodes

Math nodes represent the boundaries of a math formula, normally wrapped into `$` signs. The following fields are available: `attr`, `shrink`, `shrink_order`, `stretch`, `stretch_order`, `surround` and `width`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	<code>beginmath</code> and <code>endmath</code>
<code>attr</code>	node	list of attributes
<code>surround</code>	number	width of the <code>\mathsurround</code> kern
<code>width</code>	number	the horizontal or vertical displacement
<code>stretch</code>	number	extra (positive) displacement or stretch amount
<code>stretch_order</code>	number	factor applied to stretch amount
<code>shrink</code>	number	extra (negative) displacement or shrink amount
<code>shrink_order</code>	number	factor applied to shrink amount

The glue fields only kick in when the surround fields is zero.

9.2.8 glue nodes

Skips are about the only type of data objects in traditional TeX that are not a simple value. They are inserted when TeX sees a space in the text flow but also by `\hskip` and `\vskip`. The structure that represents the glue components of a skip internally is called a `glue_spec`. In LuaMetaTeX we don't use the spec itself but just its values. A glue node has the fields: `attr`, `font`, `leader`, `shrink`, `shrink_order`, `stretch`, `stretch_order` and `width`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	<code>abovedisplayshortskip</code> , <code>abovedisplayskip</code> , <code>baselineskip</code> , <code>belowdisplayshortskip</code> , <code>belowdisplayskip</code> , <code>cleaders</code> , <code>conditionalmathskip</code> , <code>correctionskip</code> , <code>gladders</code> , <code>indentskip</code> , <code>intermathskip</code> , <code>leaders</code> , <code>lefthangskip</code> , <code>leftskip</code> , <code>lineskip</code> , <code>mathskip</code> , <code>medmuskip</code> , <code>muglue</code> , <code>parfillleftskip</code> , <code>parfillskip</code> , <code>parskip</code> , <code>righthangskip</code> , <code>rightskip</code> , <code>spaceskip</code> , <code>splittopskip</code> , <code>tabskip</code> , <code>thickmuskip</code> , <code>thinmuskip</code> , <code>topskip</code> , <code>userskip</code> , <code>xleaders</code> , <code>xspaceskip</code> and <code>zerospaceskip</code>
<code>attr</code>	node	list of attributes
<code>leader</code>	node	pointer to a box or rule for leaders
<code>width</code>	number	the horizontal or vertical displacement
<code>stretch</code>	number	extra (positive) displacement or stretch amount
<code>stretch_order</code>	number	factor applied to stretch amount



<code>shrink</code>	number	extra (negative) displacement or shrink amount
<code>shrink_order</code>	number	factor applied to shrink amount

Note that we use the key `width` in both horizontal and vertical glue. This suits the \TeX internals well so we decided to stick to that naming.

The effective width of some glue subtypes depends on the stretch or shrink needed to make the encapsulating box fit its dimensions. For instance, in a paragraph lines normally have glue representing spaces and these stretch or shrink to make the content fit in the available space. The `effectiveglue` function that takes a glue node and a parent (hlist or vlist) returns the effective width of that glue item. When you pass `true` as third argument the value will be rounded.

9.2.9 glue_spec nodes

Internally LuaMeta \TeX (like its ancestors) also uses nodes to store data that is not seen in node lists. For instance the state of expression scanning (`\dimexpr` etc.) and conditionals (`\ifcase` etc.) is also kept in lists of nodes. A glue, which has five components, is stored in a node as well, so, where most registers store just a number, a skip register (of internal quantity) uses a pointer to a glue spec node. It has similar fields as glue nodes: `shrink`, `shrink_order`, `stretch`, `stretch_order` and `width`, which is not surprising because in the past (and other engines than Lua \TeX) a glue node also has its values stored in a glue spec. This has some advantages because often the values are the same, so for instance spacing related skips were not resolved immediately but pointed to the current value of a space related internal register (like `\spaceskip`). But, in Lua \TeX we do resolve these quantities immediately and we put the current values in the glue nodes.

FIELD	TYPE	EXPLANATION
<code>width</code>	number	the horizontal or vertical displacement
<code>stretch</code>	number	extra (positive) displacement or stretch amount
<code>stretch_order</code>	number	factor applied to stretch amount
<code>shrink</code>	number	extra (negative) displacement or shrink amount
<code>shrink_order</code>	number	factor applied to shrink amount

You will only find these nodes in a few places, for instance when you query an internal quantity. In principle we could do without them as we have interfaces that use the five numbers instead. For compatibility reasons we keep glue spec nodes exposed but this might change in the future.

9.2.10 kern nodes

The `\kern` command creates such nodes but for instance the font and math machinery can also add them. There are not that many fields: `attr`, `expansion_factor` and `kern`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	accentkern, fontkern, italiccorrection, leftmarginkern, mathlistkern, rightmarginkern and userkern
<code>attr</code>	node	list of attributes



kern	number	fixed horizontal or vertical advance
expansion_factor	number	multiplier related to hz for font kerns

9.2.11 penalty nodes

The `\penalty` command is one that generates these nodes. It is one of the type of nodes often found in vertical lists. It has the fields: `attr` and `penalty`.

FIELD	TYPE	EXPLANATION
subtype	number	afterdisplaypenalty, beforedisplaypenalty, equationnumberpenalty, finalpenalty, linebreakpenalty, linepenalty, noadpenalty, userpenalty and wordpenalty
attr	node	list of attributes
penalty	number	the penalty value

The subtypes are just informative and \TeX itself doesn't use them. When you run into an `linebreakpenalty` you need to keep in mind that it's a accumulation of `club`, `widow` and other relevant penalties.

9.2.12 glyph nodes

These are probably the mostly used nodes and although you can push them in the current list with for instance `\char` \TeX will normally do it for you when it considers some input to be text. Glyph nodes are relatively large and have many fields: `attr`, `char`, `data`, `depth`, `expansion_factor`, `font`, `height`, `hyphenate`, `language`, `left`, `lhmin`, `options`, `rhmin`, `right`, `script`, `state`, `total`, `uchyph`, `width`, `xoffset`, `xscale`, `yoffset` and `yscale`.

FIELD	TYPE	EXPLANATION
subtype	number	bit field
attr	node	list of attributes
char	number	the character index in the font
font	number	the font identifier
language	number	the language identifier
left	number	the frozen <code>\lefthyphenm</code> value
right	number	the frozen <code>\righthyphenm</code> value
uchyph	boolean	the frozen <code>\uchyph</code> value
state	number	a user field (replaces the component list)
xoffset	number	a virtual displacement in horizontal direction
yoffset	number	a virtual displacement in vertical direction
width	number	the (original) width of the character
height	number	the (original) height of the character
depth	number	the (original) depth of the character
expansion_factor	number	the to be applied expansion_factor
data	number	a general purpose field for users (we had room for it)



The width, height and depth values are read-only. The `expansion_factor` is assigned in the par builder and used in the backend. Valid bits for the subtype field are:

BIT	MEANING
0	character
1	ligature
2	ghost
3	left
4	right

The `expansion_factor` has been introduced as part of the separation between front- and backend. It is the result of extensive experiments with a more efficient implementation of expansion. Early versions of LuaTeX already replaced multiple instances of fonts in the backend by scaling but contrary to pdfTeX in LuaTeX we now also got rid of font copies in the frontend and replaced them by expansion factors that travel with glyph nodes. Apart from a cleaner approach this is also a step towards a better separation between front- and backend.

The `is_char` function checks if a node is a glyph node with a subtype still less than 256. This function can be used to determine if applying font logic to a glyph node makes sense. The value `nil` gets returned when the node is not a glyph, a character number is returned if the node is still tagged as character and `false` gets returned otherwise. When `nil` is returned, the `id` is also returned. The `is_glyph` variant doesn't check for a subtype being less than 256, so it returns either the character value or `nil` plus the `id`. These helpers are not always faster than separate calls but they sometimes permit making more readable tests. The `uses_font` helpers takes a node and font `id` and returns true when a glyph or disc node references that font.

9.2.13 boundary nodes

This node relates to the `\noboundary`, `\boundary`, `\protrusionboundary` and `\wordboundary` primitives. These are small nodes: `attr` and `data` are the only fields.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	cancel, protrusion, user and word
<code>attr</code>	node	list of attributes
<code>data</code>	number	values 0-255 are reserved

9.2.14 par nodes

This node is inserted at the start of a paragraph. You should not mess too much with this one. Valid fields are: `attr`, `box_left`, `box_left_width`, `box_right`, `box_right_width`, `brokenpenalty`, `dir` and `interlinepenalty`.

FIELD	TYPE	EXPLANATION
<code>attr</code>	node	list of attributes
<code>pen_inter</code>	number	local interline penalty (from <code>\localinterlinepenalty</code>)
<code>pen_broken</code>	number	local broken penalty (from <code>\localbrokenpenalty</code>)



<code>dir</code>	string	the direction of this par. see 9.2.15
<code>box_left</code>	node	the <code>\localleftbox</code>
<code>box_left_width</code>	number	width of the <code>\localleftbox</code>
<code>box_right</code>	node	the <code>\localrightbox</code>
<code>box_right_width</code>	number	width of the <code>\localrightbox</code>

A warning: never assign a node list to the `box_left` or `box_right` field unless you are sure its internal link structure is correct, otherwise an error may result.

9.2.15 `dir` nodes

Direction nodes mark parts of the running text that need a change of direction and the `\textdir` command generates them. Again this is a small node, we just have `attr`, `dir` and `level`.

FIELD	TYPE	EXPLANATION
<code>subtype</code>	number	<code>cancel</code> and <code>normal</code>
<code>attr</code>	node	list of attributes
<code>dir</code>	string	the direction (0 = l2r, 1 = r2l)
<code>level</code>	number	nesting level of this direction

There are only two directions: left-to-right (0) and right-to-left (1). This is different from LuaTeX that has four directions.

9.2.16 `Whatsits`

A `whatsit` node is a real simple one and it only has a `subtype`. It is even less than a `user` node (which it actually could be) and uses hardly any memory. What you do with it it entirely up to you: it's is real minimalistic. You can assign a `subtype` and it has attributes. It is all up to the user how they are handled.

9.2.17 `Math noads`

9.2.17.1 `The concept`

These are the so-called ‘`noad`’s and the nodes that are specifically associated with math processing. When you enter a formula, TeX creates a node list with regular nodes and `noads`. Then it hands over the list the math processing engine. The result of that is a `nodelist` without `noads`. Most of the `noads` contain `subnodes` so that the list of possible fields is actually quite small. Math formulas are both a linked list and a tree. For instance in $e = mc^2$ there is a linked list `e = m c` but the `c` has a superscript branch that itself can be a list with branches.

First, there are the objects (the TeXbook calls them ‘`atoms`’) that are associated with the simple math objects: `ord`, `op`, `bin`, `rel`, `open`, `close`, `punct`, `inner`, `over`, `under`, `vcenter`. These all have the same fields, and they are combined into a single node type with separate subtypes for differentiation: `attr`, `nucleus`, `options`, `sub` and `sup`.

Many object fields in math mode are either simple characters in a specific family or math lists



or node lists: `math_char`, `math_text_char`, `sub_box` and `sub_mlist` and `delimiter`. These are endpoints and therefore the `next` and `prev` fields of these subnodes are unused.

Some of the more elaborate nodes have an option field. The values in this bitset are common:

MEANING	BITS
set	0x08
internal	0x00 + 0x08
internal	0x01 + 0x08
axis	0x02 + 0x08
no axis	0x04 + 0x08
exact	0x10 + 0x08
left	0x11 + 0x08
middle	0x12 + 0x08
right	0x14 + 0x08
no subscript	0x21 + 0x08
no superscript	0x22 + 0x08
no script	0x23 + 0x08

9.2.17.2 `math_char` and `math_text_char` subnodes

These are the most common ones, as they represent characters, and they both have the same fields: `attr`, `char`, `fam` and `options`.

FIELD	TYPE	EXPLANATION
<code>attr</code>	node	list of attributes
<code>char</code>	number	the character index
<code>fam</code>	number	the family number

The `math_char` is the simplest subnode field, it contains the character and family for a single glyph object. The family eventually resolves on a reference to a font. The `math_text_char` is a special case that you will not normally encounter, it arises temporarily during math list conversion (its sole function is to suppress a following italic correction).

9.2.17.3 `sub_box` and `sub_mlist` subnodes

These two subnode types are used for subsidiary list items. For `sub_box`, the `list` points to a 'normal' vbox or hbox. For `sub_mlist`, the `list` points to a math list that is yet to be converted. Their fields are: `attr` and `list`.

FIELD	TYPE	EXPLANATION
<code>attr</code>	node	list of attributes
<code>list</code>	node	list of nodes

A warning: never assign a node list to the `list` field unless you are sure its internal link structure is correct, otherwise an error is triggered.



9.2.17.4 delimiter subnodes

There is a fifth subnode type that is used exclusively for delimiter fields. As before, the next and prev fields are unused, but we do have: attr, large_char, large_fam, small_char and small_fam.

FIELD	TYPE	EXPLANATION
attr	node	list of attributes
small_char	number	character index of base character
small_fam	number	family number of base character
large_char	number	character index of next larger character
large_fam	number	family number of next larger character

The fields large_char and large_fam can be zero, in that case the font that is set for the small_fam is expected to provide the large version as an extension to the small_char.

9.2.17.5 simple noad nodes

In these noads, the nucleus, sub and sup fields can branch of. Its fields are: attr, nucleus, options, sub and sup.

FIELD	TYPE	EXPLANATION
subtype	number	bin, close, inner, opdisplaylimits, open, oplimits, opnolimits, ord, ordlimits, over, punct, rel, under and vcenter
attr	node	list of attributes
nucleus	kernel node	base
sub	kernel node	subscript
sup	kernel node	superscript
options	number	bitset of rendering options

9.2.17.6 accent nodes

Accent nodes deal with stuff on top or below a math constructs. They support: accent, attr, bot_accent, fraction, nucleus, overlay_accent, sub, sup and top_accent.

FIELD	TYPE	EXPLANATION
subtype	number	bothflexible, fixedboth, fixedbottom and fixedtop
nucleus	kernel node	base
sub	kernel node	subscript
sup	kernel node	superscript
accent	kernel node	top accent
bot_accent	kernel node	bottom accent
fraction	number	larger step criterium (divided by 1000)

9.2.17.7 style nodes

These nodes are signals to switch to another math style. They are quite simple: attr and style. Currently the subtype is actually used to store the style but don't rely on that for the future.



Fields are: attr and style.

FIELD	TYPE	EXPLANATION
style	string	contains the style

Valid styles are: display (0), crampeddisplay (1), text (2), crampedtext (3), script (4), crampedscript (5), scriptscript (6) and crampedscriptscript (7).

9.2.17.8 parameter nodes

These nodes are used to (locally) set math parameters: list, name, style and value. Fields are: list, name, style and value.

FIELD	TYPE	EXPLANATION
style	string	contains the style
name	string	defines the parameter
value	number	holds the value, in case of a muglue multiple

9.2.17.9 choice nodes

Of its fields attr, display, script, scriptscript and text most are lists. Warning: never assign a node list unless you are sure its internal link structure is correct, otherwise an error can occur.

FIELD	TYPE	EXPLANATION
attr	node	list of attributes
display	node	list of display size alternatives
text	node	list of text size alternatives
script	node	list of scriptsize alternatives
scriptscript	node	list of scriptscriptsize alternatives

9.2.17.10 radical nodes

Radical nodes are the most complex as they deal with scripts as well as constructed large symbols. Many fields: attr, degree, left, nucleus, options, sub, sup and width. Warning: never assign a node list to the nucleus, sub, sup, left, or degree field unless you are sure its internal link structure is correct, otherwise an error can be triggered.

FIELD	TYPE	EXPLANATION
subtype	number	radical, udelimiterover, udelimiterunder, uhextensible, uoverdelimit, uradical, uroot and uunderdelimiter
attr	node	list of attributes
nucleus	kernel node	base
sub	kernel node	subscript
sup	kernel node	superscript
left	delimiter node	
degree	kernel node	only set by \Uroot



width	number	required width
options	number	bitset of rendering options

9.2.17.11 fraction nodes

Fraction nodes are also used for delimited cases, hence the left and right fields among: attr, denom, fam, left, middle, num, options, right and width.

FIELD	TYPE	EXPLANATION
attr	node	list of attributes
width	number	(optional) width of the fraction
num	kernel node	numerator
denom	kernel node	denominator
left	delimiter node	left side symbol
right	delimiter node	right side symbol
middle	delimiter node	middle symbol
options	number	bitset of rendering options

Warning: never assign a node list to the num, or denom field unless you are sure its internal link structure is correct, otherwise an error can result.

9.2.17.12 fence nodes

Fence nodes come in pairs but either one can be a dummy (this period driven empty fence). Fields are: attr, class, delimiter, depth, height, italic and options. Some of these fields are used by the renderer and might get adapted in the process.

FIELD	TYPE	EXPLANATION
subtype	number	left, middle, no, right and unset
attr	node	list of attributes
delimiter	delimiter node	delimiter specification
italic	number	italic correction
height	number	required height
depth	number	required depth
options	number	bitset of rendering options
class	number	spacing related class

9.3 The node library

9.3.1 Introduction

The node library provides methods that facilitate dealing with (lists of) nodes and their values. They allow you to create, alter, copy, delete, and insert node, the core objects within the typesetter. Nodes are represented in Lua as userdata. The various parts within a node can be accessed using named fields.



Each node has at least the three fields `next`, `id`, and `subtype`. The other available fields depend on the `id`.

- ▶ The `next` field returns the userdata object for the next node in a linked list of nodes, or `nil`, if there is no next node.
- ▶ The `id` indicates TeX's 'node type'. The field `id` has a numeric value for efficiency reasons, but some of the library functions also accept a string value instead of `id`.
- ▶ The `subtype` is another number. It often gives further information about a node of a particular `id`.

Nodes can be compared to each other, but: you are actually comparing indices into the node memory. This means that equality tests can only be trusted under very limited conditions. It will not work correctly in any situation where one of the two nodes has been freed and/or reallocated: in that case, there will be false positives. The general approach to a node related callback is as follows:

- ▶ Assume that the node list that you get is okay and properly double linked. If for some reason the links are not right, you can apply `node.slide` to the list.
- ▶ When you insert a node, make sure you use a previously removed one, a new one or a copy. Don't simply inject the same node twice.
- ▶ When you remove a node, make sure that when this is permanent, you also free the node or list.
- ▶ Although you can fool the system, normally you will trigger an error when you try to copy a nonexisting node, or free an already freed node. There is some overhead involved in this checking but the current compromise is acceptable.
- ▶ When you're done, pass back (if needed) the result. It's your responsibility to make sure that the list is properly linked (you can play safe and again apply `node.slide`. In principle you can put nodes in a list that are not acceptable in the following up actions. Some nodes get ignored, others will trigger an error, and sometimes the engine will just crash.

So, from the above it will be clear then memory management of nodes has to be done explicitly by the user. Nodes are not 'seen' by the Lua garbage collector, so you have to call the node freeing functions yourself when you are no longer in need of a node (list). Nodes form linked lists without reference counting, so you have to be careful that when control returns back to LuaTeX itself, you have not deleted nodes that are still referenced from a next pointer elsewhere, and that you did not create nodes that are referenced more than once. Normally the setters and getters handle this for you.

A good example are discretionary nodes that themselves have three sublists. Internally they use special pointers, but the user never sees them because when you query them or set fields, this property is hidden and taken care of. You just see a list. But, when you mess with these sub lists it is your responsibility that it only contains nodes that are permitted in a discretionary.

There are statistics available with regards to the allocated node memory, which can be handy for tracing. Normally the amount of used nodes is not that large. Typesetting a page can involve thousands of them but most are freed when the page has been shipped out. Compared to other programs, node memory usage is not that excessive. So, if for some reason your application leaks nodes, if at the end of your run you lost as few hundred it's not a real problem. In fact, if you created boxes and made copies but not flushed them for good reason, your run will for sure



end with used nodes and the statistics will mention that. The same is true for attributes and skips (glue spec nodes): keeping the current state involves using nodes.

9.3.2 Housekeeping

9.3.2.1 types

This function returns an array that maps node id numbers to node type strings, providing an overview of the possible top-level id types.

```
<table> t = node.types()
```

When we issue this command, we get a table. The currently visible types are { [0] = "hlist", "vlist", "rule", "insert", "mark", "adjust", "boundary", "disc", "whatsit", "par", "dir", "math", "glue", "kern", "penalty", "style", "choice", "parameter", "noad", "radical", "fraction", "accent", "fence", "math_char", "math_text_char", "sub_box", "sub_mlist", "delimiter", "glyph", "unset", [32] = "attribute_list", [33] = "attribute", [34] = "glue_spec", [35] = "temp", [36] = "split", } where the numbers are the internal identifiers. Only those nodes are reported that make sense to users so there can be gaps in the range of numbers.

9.3.2.2 id and type

This converts a single type name to its internal numeric representation.

```
<number> id = node.id(<string> type)
```

The `node.id("glyph")` command returns the number 28 and `node.id("hlist")` returns 0 where the numbers don't relate to importance or some ordering; they just appear in the order that is handy for the engine. Commands like this are rather optimized so performance should be ok but you can of course always store the id in a Lua number.

The reverse operation is: `node.type`. If the argument is a number, then the next function converts an internal numeric representation to an external string representation. Otherwise, it will return the string node if the object represents a node, and `nil` otherwise.

```
<string> type = node.type(<any> n)
```

The `node.type(4)` command returns the string `mark` and `node.id(99)` returns `nil` because there is no node with that id.

9.3.2.3 fields and hasfield

This function returns an indexed table with valid field names for a particular type of node.

```
<table> t = node.fields(<number|string> id)
```

The function accepts a string or number, so `node.fields("glyph")` returns { [-1] = "prev", [0] = "next", "id", "subtype", "attr", "char", "font", "language", "lhmin", "rhmin", "uchyph", "state", "left", "right", "xoffset", "yoffset", "xscale", "yscale",



"width", "height", "depth", "total", "expansion_factor", "data", "script", "hyphenate", "options", } and `node.fields (12)` gives { [-1] = "prev", [0] = "next", "id", "subtype", "attr", "leader", "width", "stretch", "shrink", "stretch_order", "shrink_order", "font", }.

The `hasfield` function returns a boolean that is only true if `n` is actually a node, and it has the field.

```
<boolean> t = node.hasfield(<node> n, <string> field)
```

This function probably is not that useful but some nodes don't have a subtype, attr or prev field and this is a way to test for that.

9.3.2.4 `is_node`

```
<boolean|integer> t = node.is_node(<any> item)
```

This function returns a number (the internal index of the node) if the argument is a userdata object of type `<node>` and false when no node is passed.

9.3.2.5 `new`

The `new` function creates a new node. All its fields are initialized to either zero or nil except for `id` and `subtype`. Instead of numbers you can also use strings (names). If you pass a second argument the subtype will be set too.

```
<node> n = node.new(<number|string> id)
<node> n = node.new(<number|string> id, <number|string> subtype)
```

As already has been mentioned, you are responsible for making sure that nodes created this way are used only once, and are freed when you don't pass them back somehow.

9.3.2.6 `free, flushnode and flushlist`

The next one frees node `n` from \TeX 's memory. Be careful: no checks are done on whether this node is still pointed to from a register or some next field: it is up to you to make sure that the internal data structures remain correct. Fields that point to nodes or lists are flushed too. So, when you used their content for something else you need to set them to nil first.

```
<node> next = node.free(<node> n)
flushnode(<node> n)
```

The `free` function returns the next field of the freed node, while the `flushnode` alternative returns nothing.

A list starting with node `n` can be flushed from \TeX 's memory too. Be careful: no checks are done on whether any of these nodes is still pointed to from a register or some next field: it is up to you to make sure that the internal data structures remain correct.

```
node.flushlist(<node> n)
```



When you free for instance a discretionary node, `flushlist` is applied to the `pre`, `post`, `replace` so you don't need to do that yourself. Assigning them `nil` won't free those lists!

9.3.2.7 copy and copylist

This creates a deep copy of node `n`, including all nested lists as in the case of a `hlist` or `vlist` node. Only the `next` field is not copied.

```
<node> m = node.copy(<node> n)
```

A deep copy of the node list that starts at `n` can be created too. If `m` is also given, the copy stops just before node `m`.

```
<node> m = node.copylist(<node> n)
<node> m = node.copylist(<node> n, <node> m)
```

Note that you cannot copy attribute lists this way. However, there is normally no need to copy attribute lists as when you do assignments to the `attr` field or make changes to specific attributes, the needed copying and freeing takes place automatically. When you change a value of an attribute *in* a list, it will affect all the nodes that share that list.

9.3.2.8 write

```
node.write(<node> n)
```

This function will append a node list to $\text{T}_{\text{E}}\text{X}$'s 'current list'. The node list is not deep-copied! There is no error checking either! You might need to enforce horizontal mode in order for this to work as expected.

9.3.3 Manipulating lists

9.3.3.1 slide

This helper makes sure that the node list is double linked and returns the found tail node.

```
<node> tail = node.slide(<node> n)
```

In most cases $\text{T}_{\text{E}}\text{X}$ itself only uses `next` pointers but your other callbacks might expect proper `prev` pointers too. So, when you run into issues or are in doubt, apply the `slide` function before you return the list.

9.3.3.2 tail

```
<node> m = node.tail(<node> n)
```

Returns the last node of the node list that starts at `n`.

9.3.3.3 length and count

```
<number> i = node.length(<node> n)
```



```
<number> i = node.length(<node> n, <node> m)
```

Returns the number of nodes contained in the node list that starts at `n`. If `m` is also supplied it stops at `m` instead of at the end of the list. The node `m` is not counted.

```
<number> i = node.count(<number> id, <node> n)
<number> i = node.count(<number> id, <node> n, <node> m)
```

Returns the number of nodes contained in the node list that starts at `n` that have a matching `id` field. If `m` is also supplied, counting stops at `m` instead of at the end of the list. The node `m` is not counted. This function also accept string `id`'s.

9.3.3.4 remove

```
<node> head, current, removed =
  node.remove(<node> head, <node> current)
<node> head, current =
  node.remove(<node> head, <node> current, <boolean> true)
```

This function removes the node `current` from the list following `head`. It is your responsibility to make sure it is really part of that list. The return values are the new head and current nodes. The returned current is the node following the current in the calling argument, and is only passed back as a convenience (or `nil`, if there is no such node). The returned head is more important, because if the function is called with `current` equal to `head`, it will be changed. When the third argument is passed, the node is freed.

9.3.3.5 insertbefore

```
<node> head, new = node.insertbefore(<node> head, <node> current, <node> new)
```

This function inserts the node `new` before `current` into the list following `head`. It is your responsibility to make sure that `current` is really part of that list. The return values are the (potentially mutated) head and the node `new`, set up to be part of the list (with correct next field). If `head` is initially `nil`, it will become `new`.

9.3.3.6 insertafter

```
<node> head, new = node.insertafter(<node> head, <node> current, <node> new)
```

This function inserts the node `new` after `current` into the list following `head`. It is your responsibility to make sure that `current` is really part of that list. The return values are the head and the node `new`, set up to be part of the list (with correct next field). If `head` is initially `nil`, it will become `new`.

9.3.3.7 lastnode

```
<node> n = node.lastnode()
```

This function pops the last node from `TeX`'s 'current list'. It returns that node, or `nil` if the current list is empty.



9.3.3.8 traverse

```
<node> t, id, subtype = node.traverse(<node> n)
```

This is a Lua iterator that loops over the node list that starts at n. Typically code looks like this:

```
for n in node.traverse(head) do
  ...
end
```

is functionally equivalent to:

```
do
  local n
  local function f (head,var)
    local t
    if var == nil then
      t = head
    else
      t = var.next
    end
    return t
  end
  while true do
    n = f (head, n)
    if n == nil then break end
    ...
  end
end
```

It should be clear from the definition of the function f that even though it is possible to add or remove nodes from the node list while traversing, you have to take great care to make sure all the next (and prev) pointers remain valid.

If the above is unclear to you, see the section 'For Statement' in the Lua Reference Manual.

9.3.3.9 traverse_id

```
<node> t, subtype = node.traverse_id(<number> id, <node> n)
```

This is an iterator that loops over all the nodes in the list that starts at n that have a matching id field.

See the previous section for details. The change is in the local function f, which now does an extra while loop checking against the upvalue id:

```
local function f(head,var)
  local t
  if var == nil then
    t = head
```



```

else
  t = var.next
end
while not t.id == id do
  t = t.next
end
return t
end

```

9.3.3.10 `traverse_char` and `traverse_glyph`

The `traverse_char` iterator loops over the glyph nodes in a list. Only nodes with a subtype less than 256 are seen.

```
<direct> n, font, char = node.direct.traverse_char(<direct> n)
```

The `traverse_glyph` iterator loops over a list and returns the list and filters all glyphs:

```
<direct> n, font, char = node.traverse_glyph(<direct> n)
```

These functions are only available for direct nodes.

9.3.3.11 `traverse_list`

This iterator loops over the `hlist` and `vlist` nodes in a list.

```
<direct> n, id, subtype, list = node.traverse_list(<direct> n)
```

The four return values can save some time compared to fetching these fields but in practice you seldom need them all. This function is only available for direct nodes.

9.3.3.12 `traverse_content`

This iterator loops over nodes that have content: `hlist`, `vlist`, `glue` with leaders, `glyphs`, `disc` and `rules` nodes.

```
<direct> n, id, subtype[, list|leader] = node.traverse_list(<direct> n)
```

The four return values can save some time compared to fetching these fields but in practice you seldom need them all. This function is only available for direct nodes.

9.3.3.13 Reverse traversing

The traversers also support backward traversal. An optional extra boolean triggers this. Yet another optional boolean will automatically start at the end of the given list.

```
\setbox0\hbox{1 2 3 4 5}
```

```
local l = tex.box[0].list
for n in node.traverse(l) do
```



```

    print("1>",n)
end
for n in node.traverse(l,true) do
    print("2>",n)
end
for n in node.traverse(l,true,true) do
    print("3>",n)
end
for n in node.traverse_id(nodes.nodecodes.glyph,l) do
    print("4>",n)
end
for n in node.traverse_id(nodes.nodecodes.glyph,l,true) do
    print("5>",n)
end
for n in node.traverse_id(nodes.nodecodes.glyph,l,true,true) do
    print("6>",n)
end

```

This produces something similar to this (the glyph subtype indicates that it has been processed by the font handlers):

```

1>    <node :    nil <=    1112 =>    590 : glyph 32768>
1>    <node :    1112 <=    590 =>    1120 : glue spaceskip>
1>    <node :    590 <=    1120 =>    849 : glyph 32768>
1>    <node :    1120 <=    849 =>    1128 : glue spaceskip>
1>    <node :    849 <=    1128 =>    880 : glyph 32768>
1>    <node :    1128 <=    880 =>    1136 : glue spaceskip>
1>    <node :    880 <=    1136 =>    1020 : glyph 32768>
1>    <node :    1136 <=    1020 =>    1144 : glue spaceskip>
1>    <node :    1020 <=    1144 =>    nil : glyph 32768>
2>    <node :    nil <=    1112 =>    590 : glyph 32768>
3>    <node :    1020 <=    1144 =>    nil : glyph 32768>
3>    <node :    1136 <=    1020 =>    1144 : glue spaceskip>
3>    <node :    880 <=    1136 =>    1020 : glyph 32768>
3>    <node :    1128 <=    880 =>    1136 : glue spaceskip>
3>    <node :    849 <=    1128 =>    880 : glyph 32768>
3>    <node :    1120 <=    849 =>    1128 : glue spaceskip>
3>    <node :    590 <=    1120 =>    849 : glyph 32768>
3>    <node :    1112 <=    590 =>    1120 : glue spaceskip>
3>    <node :    nil <=    1112 =>    590 : glyph 32768>
4>    <node :    nil <=    1112 =>    590 : glyph 32768>
4>    <node :    590 <=    1120 =>    849 : glyph 32768>
4>    <node :    849 <=    1128 =>    880 : glyph 32768>
4>    <node :    880 <=    1136 =>    1020 : glyph 32768>
4>    <node :    1020 <=    1144 =>    nil : glyph 32768>
5>    <node :    nil <=    1112 =>    590 : glyph 32768>
6>    <node :    1020 <=    1144 =>    nil : glyph 32768>

```



```

6> <node :      880 <=   1136 =>   1020 : glyph 32768>
6> <node :      849 <=   1128 =>     880 : glyph 32768>
6> <node :      590 <=   1120 =>     849 : glyph 32768>
6> <node :      nil <=   1112 =>     590 : glyph 32768>

```

9.3.3.14 find_node

This helper returns the location of the first match at or after node n:

```

<node> n = node.find_node(<node> n, <integer> subtype)
<node> n, subtype = node.find_node(<node> n)

```

9.3.4 Glue handling

9.3.4.1 setglue

You can set the five properties of a glue in one go. If a non-numeric value is passed the property becomes zero.

```

node.setglue(<node> n)
node.setglue(<node> n,width,stretch,shrink,stretch_order,shrink_order)

```

When you pass values, only arguments that are numbers are assigned so

```
node.setglue(n,655360,false,65536)
```

will only adapt the width and shrink.

When a list node is passed, you set the glue, order and sign instead.

9.3.4.2 getglue

The next call will return 5 values or nothing when no glue is passed.

```

<integer> width, <integer> stretch, <integer> shrink, <integer> stretch_order,
  <integer> shrink_order = node.getglue(<node> n)

```

When the second argument is false, only the width is returned (this is consistent with `tex.get`).

When a list node is passed, you get back the glue that is set, the order of that glue and the sign.

9.3.4.3 iszeroglue

This function returns true when the width, stretch and shrink properties are zero.

```
<boolean> isglue = node.iszeroglue(<node> n)
```



9.3.5 Attribute handling

9.3.5.1 Attributes

Assignments to attributes registers result in assigning lists with set attributes to nodes and the implementation is non-trivial because the value that is attached to a node is essentially a (sorted) sparse array of key-value pairs. It is generally easiest to deal with attribute lists and attributes by using the dedicated functions in the node library.

9.3.5.2 `attribute_list` nodes

An `attribute_list` item is used as a head pointer for a list of attribute items. It has only one user-visible field:

FIELD	TYPE	EXPLANATION
<code>next</code>	<code>node</code>	pointer to the first attribute

9.3.5.3 `attr` nodes

A normal node's attribute field will point to an item of type `attribute_list`, and the `next` field in that item will point to the first defined 'attribute' item, whose `next` will point to the second 'attribute' item, etc.

FIELD	TYPE	EXPLANATION
<code>next</code>	<code>node</code>	pointer to the next attribute
<code>number</code>	<code>number</code>	the attribute type id
<code>value</code>	<code>number</code>	the attribute value

As mentioned it's better to use the official helpers rather than edit these fields directly. For instance the `prev` field is used for other purposes and there is no double linked list.

9.3.5.4 `currentattr`

This returns the currently active list of attributes, if there is one.

```
<node> m = node.currentattr()
```

The intended usage of `currentattr` is as follows:

```
local x1 = node.new("glyph")
x1.attr = node.currentattr()
local x2 = node.new("glyph")
x2.attr = node.currentattr()
```

or:

```
local x1 = node.new("glyph")
local x2 = node.new("glyph")
local ca = node.currentattr()
```



```
x1.attr = ca
x2.attr = ca
```

The attribute lists are ref counted and the assignment takes care of incrementing the refcount. You cannot expect the value `ca` to be valid any more when you assign attributes (using `tex.setattribute`) or when control has been passed back to `TEX`.

9.3.5.5 `hasattribute`

```
<number> v = node.hasattribute(<node> n, <number> id)
<number> v = node.hasattribute(<node> n, <number> id, <number> val)
```

Tests if a node has the attribute with number `id` set. If `val` is also supplied, also tests if the value matches `val`. It returns the value, or, if no match is found, `nil`.

9.3.5.6 `getattribute`

```
<number> v = node.getattribute(<node> n, <number> id)
```

Tests if a node has an attribute with number `id` set. It returns the value, or, if no match is found, `nil`. If no `id` is given then the zero attributes is assumed.

9.3.5.7 `findattribute`

```
<number> v, <node> n = node.findattribute(<node> n, <number> id)
```

Finds the first node that has attribute with number `id` set. It returns the value and the node if there is a match and otherwise nothing.

9.3.5.8 `setattribute`

```
node.setattribute(<node> n, <number> id, <number> val)
```

Sets the attribute with number `id` to the value `val`. Duplicate assignments are ignored.

9.3.5.9 `unsetattribute`

```
<number> v =
  node.unsetAttribute(<node> n, <number> id)
<number> v =
  node.unsetAttribute(<node> n, <number> id, <number> val)
```

Unsets the attribute with number `id`. If `val` is also supplied, it will only perform this operation if the value matches `val`. Missing attributes or attribute-value pairs are ignored.

If the attribute was actually deleted, returns its old value. Otherwise, returns `nil`.



9.3.6 Glyph handling

9.3.6.1 firstglyph

```
<node> n = node.firstglyph(<node> n)
<node> n = node.firstglyph(<node> n, <node> m)
```

Returns the first node in the list starting at `n` that is a glyph node with a subtype indicating it is a glyph, or `nil`. If `m` is given, processing stops at (but including) that node, otherwise processing stops at the end of the list.

9.3.6.2 is_char and is_glyph

The subtype of a glyph node signals if the glyph is already turned into a character reference or not.

```
<boolean> b = node.is_char(<node> n)
<boolean> b = node.is_glyph(<node> n)
```

9.3.6.3 hasglyph

This function returns the first glyph or disc node in the given list:

```
<node> n = node.hasglyph(<node> n)
```

9.3.6.4 ligaturing

```
<node> h, <node> t, <boolean> success = node.ligaturing(<node> n)
<node> h, <node> t, <boolean> success = node.ligaturing(<node> n, <node> m)
```

Apply T_EX-style ligaturing to the specified nodelist. The tail node `m` is optional. The two returned nodes `h` and `t` are the new head and tail (both `n` and `m` can change into a new ligature).

9.3.6.5 kerning

```
<node> h, <node> t, <boolean> success = node.kerning(<node> n)
<node> h, <node> t, <boolean> success = node.kerning(<node> n, <node> m)
```

Apply T_EX-style kerning to the specified node list. The tail node `m` is optional. The two returned nodes `h` and `t` are the head and tail (either one of these can be an inserted kern node, because special kernings with word boundaries are possible).

9.3.6.6 unprotectglyph[s]

```
node.unprotectglyph(<node> n)
node.unprotectglyphs(<node> n, [<node> n])
```

Subtracts 256 from all glyph node subtypes. This and the next function are helpers to convert from characters to glyphs during node processing. The second argument is optional and indicates the end of a range.



9.3.6.7 protectglyph[s]

```
node.protectglyph(<node> n)
node.protectglyphs(<node> n, [<node> n])
```

Adds 256 to all glyph node subtypes in the node list starting at *n*, except that if the value is 1, it adds only 255. The special handling of 1 means that characters will become glyphs after subtraction of 256. A single character can be marked by the singular call. The second argument is optional and indicates the end of a range.

9.3.6.8 protrusionskippable

```
<boolean> skippable = node.protrusionskippable(<node> n)
```

Returns true if, for the purpose of line boundary discovery when character protrusion is active, this node can be skipped.

9.3.6.9 checkdiscretionary, checkdiscretionaries

When you fool around with disc nodes you need to be aware of the fact that they have a special internal data structure. As long as you reassign the fields when you have extended the lists it's ok because then the tail pointers get updated, but when you add to list without reassigning you might end up in trouble when the linebreak routine kicks in. You can call this function to check the list for issues with disc nodes.

```
node.checkdiscretionary(<node> n)
node.checkdiscretionaries(<node> head)
```

The plural variant runs over all disc nodes in a list, the singular variant checks one node only (it also checks if the node is a disc node).

9.3.6.10 flattendiscretionaries

This function will remove the discretionaries in the list and inject the replace field when set.

```
<node> head, count = node.flattendiscretionaries(<node> n)
```

9.3.7 Packaging

9.3.7.1 hpack

This function creates a new hlist by packaging the list that begins at node *n* into a horizontal box. With only a single argument, this box is created using the natural width of its components. In the three argument form, *info* must be either `additional` or `exactly`, and *w* is the additional (`\hbox spread`) or exact (`\hbox to`) width to be used. The second return value is the badness of the generated box.

```
<node> h, <number> b =
  node.hpack(<node> n)
```



```

<node> h, <number> b =
    node.hpack(<node> n, <number> w, <string> info)
<node> h, <number> b =
    node.hpack(<node> n, <number> w, <string> info, <string> dir)

```

Caveat: there can be unexpected side-effects to this function, like updating some of the `\marks` and `\inserts`. Also note that the content of `h` is the original node list `n`: if you call `node.free(h)` you will also free the node list itself, unless you explicitly set the `list` field to `nil` beforehand. And in a similar way, calling `node.free(n)` will invalidate `h` as well!

9.3.7.2 vpack

This function creates a new `vlist` by packaging the list that begins at node `n` into a vertical box. With only a single argument, this box is created using the natural height of its components. In the three argument form, `info` must be either `additional` or `exactly`, and `w` is the additional (`\vbox spread`) or exact (`\vbox to`) height to be used.

```

<node> h, <number> b =
    node.vpack(<node> n)
<node> h, <number> b =
    node.vpack(<node> n, <number> w, <string> info)
<node> h, <number> b =
    node.vpack(<node> n, <number> w, <string> info, <string> dir)

```

The second return value is the badness of the generated box. See the description of `hpack` for a few memory allocation caveats.

9.3.7.3 prepend_prevdepth

This function is somewhat special in the sense that it is an experimental helper that adds the interlinespace to a line keeping the `baselineskip` and `lineskip` into account.

```

<node> n, <number> delta =
    node.prepend_prevdepth(<node> n, <number> prevdepth)

```

9.3.7.4 dimensions, rangedimensions, naturalwidth

```

<number> w, <number> h, <number> d =
    node.dimensions(<node> n)
<number> w, <number> h, <number> d =
    node.dimensions(<node> n, <node> t)

```

This function calculates the natural in-line dimensions of the node list starting at node `n` and terminating just before node `t` (or the end of the list, if there is no second argument). The return values are scaled points. An alternative format that starts with glue parameters as the first three arguments is also possible:

```

<number> w, <number> h, <number> d =
    node.dimensions(<number> glue_set, <number> glue_sign, <number> glue_order,

```



```

    <node> n)
<number> w, <number> h, <number> d =
    node.dimensions(<number> glue_set, <number> glue_sign, <number> glue_order,
    <node> n, <node> t)

```

This calling method takes glue settings into account and is especially useful for finding the actual width of a sublist of nodes that are already boxed, for example in code like this, which prints the width of the space in between the a and b as it would be if `\box0` was used as-is:

```

\setbox0 = \hbox to 20pt {a b}

\directlua{print (node.dimensions(
    tex.box[0].glue_set,
    tex.box[0].glue_sign,
    tex.box[0].glue_order,
    tex.box[0].head.next,
    node.tail(tex.box[0].head)
)) }

```

You need to keep in mind that this is one of the few places in \TeX where floats are used, which means that you can get small differences in rounding when you compare the width reported by `hpack` with `dimensions`.

The second alternative saves a few lookups and can be more convenient in some cases:

```

<number> w, <number> h, <number> d =
    node.rangedimensions(<node> parent, <node> first)
<number> w, <number> h, <number> d =
    node.rangedimensions(<node> parent, <node> first, <node> last)

```

A simple and somewhat more efficient variant is this:

```

<number> w =
    node.naturalwidth(<node> start, <node> stop)

```

9.3.8 Math

9.3.8.1 `mlisttohlist`

```

<node> h =
    node.mlisttohlist(<node> n, <string> display_type, <boolean> penalties)

```

This runs the internal `mlist` to `hlist` conversion, converting the math list in `n` into the horizontal list `h`. The interface is exactly the same as for the callback `mlisttohlist`.

9.3.8.2 `end_of_math`

```

<node> t = node.end_of_math(<node> start)

```



Looks for and returns the next `math_node` following the `start`. If the given node is a math end node this helper returns that node, else it follows the list and returns the next math endnote. If no such node is found `nil` is returned.

9.4 Two access models

Deep down in \TeX a node has a number which is a numeric entry in a memory table. In fact, this model, where \TeX manages memory is real fast and one of the reasons why plugging in callbacks that operate on nodes is quite fast too. Each node gets a number that is in fact an index in the memory table and that number often is reported when you print node related information. You go from userdata nodes and there numeric references and back with:

```
<integer> d = node.todirect(<node> n)
<node> n = node.tonode(<integer> d)
```

The userdata model is rather robust as it is a virtual interface with some additional checking while the more direct access which uses the node numbers directly. However, even with userdata you can get into troubles when you free nodes that are no longer allocated or mess up lists. if you apply `tostring` to a node you see its internal (direct) number and id.

The first model provides key based access while the second always accesses fields via functions:

```
nodeobject.char
getfield(nodenum, "char")
```

If you use the direct model, even if you know that you deal with numbers, you should not depend on that property but treat it as an abstraction just like traditional nodes. In fact, the fact that we use a simple basic datatype has the penalty that less checking can be done, but less checking is also the reason why it's somewhat faster. An important aspect is that one cannot mix both methods, but you can cast both models. So, multiplying a node number makes no sense.

So our advice is: use the indexed (table) approach when possible and investigate the direct one when speed might be a real issue. For that reason $\text{Lua}\TeX$ also provide the `get*` and `set*` functions in the top level node namespace. There is a limited set of getters. When implementing this direct approach the regular index by key variant was also optimized, so direct access only makes sense when nodes are accessed millions of times (which happens in some font processing for instance).

We're talking mostly of getters because setters are less important. Documents have not that many content related nodes and setting many thousands of properties is hardly a burden contrary to millions of consultations.

Normally you will access nodes like this:

```
local next = current.next
if next then
    -- do something
end
```

Here `next` is not a real field, but a virtual one. Accessing it results in a metatable method being



called. In practice it boils down to looking up the node type and based on the node type checking for the field name. In a worst case you have a node type that sits at the end of the lookup list and a field that is last in the lookup chain. However, in successive versions of LuaTeX these lookups have been optimized and the most frequently accessed nodes and fields have a higher priority. Because in practice the next accessor results in a function call, there is some overhead involved. The next code does the same and performs a tiny bit faster (but not that much because it is still a function call but one that knows what to look up).

```
local next = node.next(current)
if next then
    -- do something
end
```

In the direct namespace there are more helpers and most of them are accompanied by setters. The getters and setters are clever enough to see what node is meant. We don't deal with whatsit nodes: their fields are always accessed by name. It doesn't make sense to add getters for all fields, we just identifier the most likely candidates. In complex documents, many node and fields types never get seen, or seen only a few times, but for instance glyphs are candidates for such optimization. The `node.direct` interface has some more helpers.⁵

The `setdisc` helper takes three (optional) arguments plus an optional fourth indicating the sub-type. Its `getdisc` takes an optional boolean; when its value is `true` the tail nodes will also be returned. The `setfont` helper takes an optional second argument, it being the character. The `directmode` setter `setlink` takes a list of nodes and will link them, thereby ignoring `nil` entries. The first valid node is returned (beware: for good reason it assumes single nodes). For rarely used fields no helpers are provided and there are a few that probably are used seldom too but were added for consistency. You can of course always define additional accessors using `getfield` and `setfield` with little overhead. When the second argument of `setattributelist` is `true` the current attribute list is assumed.

The `reverse` function reverses a given list. The `exchange` function swaps two nodes; it takes upto three arguments: a head node, and one or two to be swapped nodes. When there is no third argument, it will assume that the node following node is to be used. So we have:

```
head = node.direct.reverse(head)
head = node.direct.exchange(head, first, [second])
```

In ConTeXt some of the not performance-critical userdata variants are emulated in Lua and not in the engine, so we retain downward compatibility.

FUNCTION	NODE	DIRECT	emulated
<code>checkdiscretionaries</code>	-	+	+
<code>checkdiscretionary</code>	-	+	+
<code>copylist</code>	+	+	
<code>copy</code>	+	+	
<code>count</code>	-	+	+

⁵ We can define the helpers in the node namespace with `getfield` which is about as efficient, so at some point we might provide that as module.



currentattributes	+	+	
dimensions	-	+	+
effectiveglue	-	+	+
endofmath	-	+	+
findattributerange	-	+	
findattribute	-	+	+
findnode	-	+	
firstglyph	-	+	+
flattendiscretionaries	-	+	+
flushlist	+	+	
flushnode	+	+	
free	+	+	
getattributes	-	+	
getattribute	+	+	
getpropertystable	+	+	
getsynctexfields	-	+	
getattributelist	-	+	
getboth	-	+	
getbox	-	+	
getchar	-	+	
getdata	-	+	
getdepth	-	+	
getdirection	-	+	
getdisc	-	+	
getexpansion	-	+	
getfam	-	+	
getfield	+	+	
getfont	-	+	
getglue	-	+	+
getglyphdata	-	+	
getglyphdimensions	-	+	+
getglyphscript	-	+	
getglyphstate	-	+	
getheight	-	+	
getid	-	+	
getindex	-	+	
getkerndimension	-	+	+
getkern	-	+	
getlanguage	-	+	
getleader	-	+	
getlist	-	+	
getnext	-	+	
getnormalizedline	-	+	
getnucleus	-	+	
getoffsets	-	+	
getoptions	-	+	



getorientation	-	+	
getparstate	-	+	
getpenalty	-	+	
getpost	-	+	
getprev	-	+	
getpre	-	+	
getproperty	+	+	
getreplace	-	+	
getscales	-	+	
getscript	-	+	
getshift	-	+	
getstate	-	+	
getsubpre	-	+	
getsubtype	-	+	
getsub	-	+	
getsuppre	-	+	
getsup	-	+	
gettotal	+	+	
getwhd	-	+	
getwidth	-	+	
getxscale	-	+	
getxyscale	-	+	
getyscale	-	+	
hasattribute	+	+	
hasdimensions	-	+	
hasfield	+	+	
hasglyphoption	-	+	+
hasglyph	-	+	+
hpack	-	+	+
hyphenating	-	+	+
ignoremathskip	-	+	
insertafter	+	+	
insertbefore	+	+	
ischar	-	+	
isdirect	-	+	
isglyph	-	+	
isnextchar	-	+	
isnextglyph	-	+	
isnode	+	+	
isprevchar	-	+	
isprevglyph	-	+	
isvalid	-	+	
iszeroglue	-	+	+
kerning	-	+	+
lastnode	-	+	+
length	-	+	+



ligaturing	-	+	+
makeextensible	-	+	+
migrate	-	+	
mlisttohlist	-	+	+
naturalwidth	-	+	+
new	+	+	
protectglyphs	-	+	+
protectglyph	-	+	+
protrusionskipable	-	+	+
rangedimensions	-	+	+
remove	+	+	
setattributes	-	+	
setattribute	+	+	
setsynctexfields	-	+	
setattributelist	-	+	
setboth	-	+	
setbox	-	+	
setchar	-	+	
setdata	-	+	
setdepth	-	+	
setdirection	-	+	
setdisc	-	+	
setexpansion	-	+	
setfam	-	+	
setfield	+	+	
setfont	-	+	
setglue	+	+	
setglyphdata	-	+	
setglyphscript	-	+	
setglyphstate	-	+	
setheight	-	+	
setindex	-	+	
setkern	-	+	
setlanguage	-	+	
setleader	-	+	
setlink	-	+	
setlist	-	+	
setnext	-	+	
setnucleus	-	+	
setoffsets	-	+	
setoptions	-	+	
setorientation	-	+	
setpenalty	-	+	
setpost	-	+	
setprev	-	+	
setpre	-	+	



setProperty	+	+	
setreplace	-	+	
setscales	-	+	
setscript	-	+	
setshift	-	+	
setsplit	-	+	
setstate	-	+	
setsubpre	-	+	
setsubtype	-	+	
setsub	-	+	
setsuppre	-	+	
setup	-	+	
setwhd	-	+	
setWidth	-	+	
slide	-	+	+
startofpar	-	+	
subtype	-	-	
tail	+	+	
todirect	-	+	
tonode	-	+	
tostring	+	-	
total	-	+	
tovaliddirect	-	+	
traverse_char	+	+	
traverse_content	+	+	
traverse_glyph	+	+	
traverse_id	+	+	
traverse_list	+	+	
traverse	+	+	
type	+	-	
unprotectglyphs	-	+	+
unprotectglyph	-	+	+
unsetattributes	-	+	
unsetattribute	+	+	
usedlist	-	+	+
usesfont	-	+	+
verticalbreak	-	+	
vpack	-	+	+
write	+	+	

The `node.next` and `node.prev` functions will stay but for consistency there are variants called `getnext` and `getprev`. We had to use `get` because `node.id` and `node.subtype` are already taken for providing meta information about nodes. Note: The getters do only basic checking for valid keys. You should just stick to the keys mentioned in the sections that describe node properties.

Some of the getters and setters handle multiple node types, given that the field is relevant. In that case, some field names are considered similar (like `kern` and `width`, or `data` and `value`). In



retrospect we could have normalized field names better but we decided to stick to the original (internal) names as much as possible. After all, at the Lua end one can easily create synonyms.

Some nodes have indirect references. For instance a math character refers to a family instead of a font. In that case we provide a virtual font field as accessor. So, `getfont` and `.font` can be used on them. The same is true for the width, height and depth of glue nodes. These actually access the spec node properties, and here we can set as well as get the values.

In some places Lua \TeX can do a bit of extra checking for valid node lists and you can enable that with:

```
node.fix_node_lists(<boolean> b)
```

You can set and query the Sync \TeX fields, a file number aka tag and a line number, for a glue, kern, hlist, vlist, rule and math nodes as well as glyph nodes (although this last one is not used in native Sync \TeX).

```
node.setsynctexfields(<integer> f, <integer> l)
<integer> f, <integer> l =
  node.getsynctexfields(<node> n)
```

Of course you need to know what you're doing as no checking on sane values takes place. Also, the synctex interpreter used in editors is rather peculiar and has some assumptions (heuristics).

9.5 Normalization

As an experiment the lines resulting from paragraph construction can be normalized. There are several modes, that can be set and queried with:

```
node.direct.setnormalize(<integer> n)
<integer> n = node.direct.getnormalize()
```

The state of a line (a hlist) can be queried with:

```
<integer> leftskip, <integer> rightskip,
  <integer> lefthangskip, <integer> righthangskip,
  <node> head, <node> tail,
  <integer> parindent, <integer> parfillskip = node.direct.getnormalized()
```

The modes accumulate, so mode 4 includes 1 upto 3:

VALUE	EXPLANATION
1	left and right skips and directions
2	indentation and parfill skip
3	hanging indentation and par shapes
4	idem but before left and right skips
5	inject compensation for overflow

This is experimental code and might take a while to become frozen.



9.6 Properties

Attributes are a convenient way to relate extra information to a node. You can assign them at the \TeX end as well as at the Lua end and consult them at the Lua end. One big advantage is that they obey grouping. They are linked lists and normally checking for them is pretty efficient, even if you use a lot of them. A macro package has to provide some way to manage these attributes at the \TeX end because otherwise clashes in their usage can occur.

Each node also can have a properties table and you can assign values to this table using the `setproperty` function and get properties using the `getproperty` function. Managing properties is way more demanding than managing attributes.

Take the following example:

```
\directlua {
  local n = node.new("glyph")

  node.setproperty(n, "foo")
  print(node.getproperty(n))

  node.setproperty(n, "bar")
  print(node.getproperty(n))

  node.free(n)
}
```

This will print `foo` and `bar` which in itself is not that useful when multiple mechanisms want to use this feature. A variant is:

```
\directlua {
  local n = node.new("glyph")

  node.setproperty(n, { one = "foo", two = "bar" })
  print(node.getproperty(n).one)
  print(node.getproperty(n).two)

  node.free(n)
}
```

This time we store two properties with the node. It really makes sense to have a table as property because that way we can store more. But in order for that to work well you need to do it this way:

```
\directlua {
  local n = node.new("glyph")

  local t = node.getproperty(n)

  if not t then
```



```

        t = { }
        node.setProperty(n,t)
    end
    t.one = "foo"
    t.two = "bar"

    print(node.getProperty(n).one)
    print(node.getProperty(n).two)

    node.free(n)
}

```

Here our own properties will not overwrite other users properties unless of course they use the same keys. So, eventually you will end up with something:

```

\directlua {
    local n = node.new("glyph")

    local t = node.getProperty(n)

    if not t then
        t = { }
        node.setProperty(n,t)
    end
    t.myself = { one = "foo", two = "bar" }

    print(node.getProperty(n).myself.one)
    print(node.getProperty(n).myself.two)

    node.free(n)
}

```

This assumes that only you use `myself` as subtable. The possibilities are endless but care is needed. For instance, the generic font handler that ships with `ConTeXt` uses the injections `subtable` and you should not mess with that one!

There are a few helper functions that you normally should not touch as user: `getpropertystable` and will give the table that stores properties (using direct entries) and you can best not mess too much with that one either because `LuaTeX` itself will make sure that entries related to nodes will get wiped when nodes get freed, so that the Lua garbage collector can do its job. In fact, the main reason why we have this mechanism is that it saves the user (or macro package) some work. One can easily write a property mechanism in Lua where after a shipout properties gets cleaned up but it's not entirely trivial to make sure that with each freed node also its properties get freed, due to the fact that there can be nodes left over for a next page. And having a callback bound to the node deallocator would add way to much overhead.

When we copy a node list that has a table as property, there are several possibilities: we do the same as a new node, we copy the entry to the table in properties (a reference), we do a deep copy



of a table in the properties, we create a new table and give it the original one as a metatable. After some experiments (that also included timing) with these scenarios we decided that a deep copy made no sense, nor did nilling. In the end both the shallow copy and the metatable variant were both ok, although the second one is slower. The most important aspect to keep in mind is that references to other nodes in properties no longer can be valid for that copy. We could use two tables (one unique and one shared) or metatables but that only complicates matters.

When defining a new node, we could already allocate a table but it is rather easy to do that at the lua end e.g. using a metatable `__index` method. That way it is under macro package control. When deleting a node, we could keep the slot (e.g. setting it to false) but it could make memory consumption raise unneeded when we have temporary large node lists and after that only small lists. Both are not done.

So in the end this is what happens now: when a node is copied, and it has a table as property, the new node will share that table. If the second argument of `set_properties_mode` is `true` then a metatable approach is chosen: the copy gets its own table with the original table as metatable. If you use the generic font loader the mode is enabled that way.

A few more experiments were done. For instance: copy attributes to the properties so that we have fast access at the Lua end. In the end the overhead is not compensated by speed and convenience, in fact, attributes are not that slow when it comes to accessing them. So this was rejected.

Another experiment concerned a bitset in the node but again the gain compared to attributes was neglectable and given the small amount of available bits it also demands a pretty strong agreement over what bit represents what, and this is unlikely to succeed in the T_EX community. It doesn't pay off.

Just in case one wonders why properties make sense: it is not so much speed that we gain, but more convenience: storing all kinds of (temporary) data in attributes is no fun and this mechanism makes sure that properties are cleaned up when a node is freed. Also, the advantage of a more or less global properties table is that we stay at the Lua end. An alternative is to store a reference in the node itself but that is complicated by the fact that the register has some limitations (no numeric keys) and we also don't want to mess with it too much.





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10 Lua callbacks

10.1 Registering callbacks

The callbacks are a moving target. Don't bother me with questions about them.

This library has functions that register, find and list callbacks. Callbacks are Lua functions that are called in well defined places. There are two kinds of callbacks: those that mix with existing functionality, and those that (when enabled) replace functionality. In mosty cases the second category is expected to behave similar to the built in functionality because in a next step specific data is expected. For instance, you can replace the hyphenation routine. The function gets a list that can be hyphenated (or not). The final list should be valid and is (normally) used for constructing a paragraph. Another function can replace the ligature builder and/or kerner. Doing something else is possible but in the end might not give the user the expected outcome.

The first thing you need to do is registering a callback:

```
id = callback.register(<string> callback_name, <function> func)
id = callback.register(<string> callback_name, nil)
id = callback.register(<string> callback_name, false)
```

Here the `callback_name` is a predefined callback name, see below. The function returns the internal id of the callback or `nil`, if the callback could not be registered.

LuaTeX internalizes the callback function in such a way that it does not matter if you redefine a function accidentally.

Callback assignments are always global. You can use the special value `nil` instead of a function for clearing the callback.

For some minor speed gain, you can assign the boolean `false` to the non-file related callbacks, doing so will prevent LuaTeX from executing whatever it would execute by default (when no callback function is registered at all). Be warned: this may cause all sorts of grief unless you know *exactly* what you are doing!

```
<table> info =
  callback.list()
```

The keys in the table are the known callback names, the value is a boolean where `true` means that the callback is currently set (active).

```
<function> f = callback.find(callback_name)
```

If the callback is not set, `find` returns `nil`. The `known` function can be used to check if a callback is supported.

```
if callback.known("foo") then ... end
```



10.2 File related callbacks

10.2.1 find_format_file and find_log_file

These callbacks are called as:

```
<string> actualname =  
  function (<string> askedname)
```

The askedname is a format file for reading (the format file for writing is always opened in the current directory) or a log file for writing.

10.2.2 open_data_file

This callback function gets a filename passed:

```
<table> env = function (<string> filename)
```

The return value is either the boolean value false or a table with two functions. A mandate reader function will be called once for each new line to be read, the optional close function will be called once LuaTeX is done with the file.

LuaTeX never looks at the rest of the table, so you can use it to store your private per-file data. Both the callback functions will receive the table as their only argument.

10.3 Data processing callbacks

10.3.1 process_jobname

This callback allows you to change the jobname given by `\jobname` in TeX and `tex.jobname` in Lua. It does not affect the internal job name or the name of the output or log files.

```
function(<string> jobname)  
  return <string> adjusted_jobname  
end
```

The only argument is the actual job name; you should not use `tex.jobname` inside this function or infinite recursion may occur. If you return `nil`, LuaTeX will pretend your callback never happened. This callback does not replace any internal code.



10.4 Node list processing callbacks

The description of nodes and node lists is in chapter 9.

10.4.1 `contribute_filter`

This callback is called when LuaTeX adds contents to list:

```
function(<string> extrainfo)
end
```

The string reports the group code. From this you can deduce from what list you can give a treat.

VALUE	EXPLANATION
<code>pre_box</code>	interline material is being added
<code>pre_adjust</code>	<code>\vadjust</code> material is being added
<code>box</code>	a typeset box is being added (always called)
<code>adjust</code>	<code>\vadjust</code> material is being added

10.4.2 `buildpage_filter`

This callback is called whenever LuaTeX is ready to move stuff to the main vertical list. You can use this callback to do specialized manipulation of the page building stage like imposition or column balancing.

```
function(<string> extrainfo)
end
```

The string `extrainfo` gives some additional information about what TeX's state is with respect to the 'current page'. The possible values for the `buildpage_filter` callback are:

VALUE	EXPLANATION
<code>alignment</code>	a (partial) alignment is being added
<code>after_output</code>	an output routine has just finished
<code>new_graf</code>	the beginning of a new paragraph
<code>vmode_par</code>	<code>\par</code> was found in vertical mode
<code>hmode_par</code>	<code>\par</code> was found in horizontal mode
<code>insert</code>	an insert is added
<code>penalty</code>	a penalty (in vertical mode)
<code>before_display</code>	immediately before a display starts
<code>after_display</code>	a display is finished
<code>end</code>	LuaTeX is terminating (it's all over)

10.4.3 `build_page_insert`

This callback is called when the pagebuilder adds an insert. There is not much control over this



mechanism but this callback permits some last minute manipulations of the spacing before an insert, something that might be handy when for instance multiple inserts (types) are appended in a row.

```
function(<number> n, <number> i)
    return <number> register
end
```

with

VALUE	EXPLANATION
n	the insert class
i	the order of the insert

The return value is a number indicating the skip register to use for the prepended spacing. This permits for instance a different top space (when i equals one) and intermediate space (when i is larger than one). Of course you can mess with the insert box but you need to make sure that LuaTeX is happy afterwards.

10.4.4 pre_linebreak_filter

This callback is called just before LuaTeX starts converting a list of nodes into a stack of \hboxes, after the addition of \parfillskip.

```
function(<node> head, <string> groupcode)
    return <node> newhead
end
```

The string called groupcode identifies the nodelist's context within TeX's processing. The range of possibilities is given in the table below, but not all of those can actually appear in pre_linebreak_filter, some are for the hpack_filter and vpack_filter callbacks that will be explained in the next two paragraphs.

VALUE	EXPLANATION
<empty>	main vertical list
hbox	\hbox in horizontal mode
adjusted_hbox	\hbox in vertical mode
vbox	\vbox
vtop	\vtop
align	\halign or \valign
disc	discretionaries
insert	packaging an insert
vcenter	\vcenter
local_box	\localleftbox or \localrightbox
split_off	top of a \vsplit
split_keep	remainder of a \vsplit



<code>align_set</code>	alignment cell
<code>fin_row</code>	alignment row

As for all the callbacks that deal with nodes, the return value can be one of three things:

- ▶ boolean true signals successful processing
- ▶ `<node>` signals that the 'head' node should be replaced by the returned node
- ▶ boolean false signals that the 'head' node list should be ignored and flushed from memory

This callback does not replace any internal code.

10.4.5 `linebreak_filter`

This callback replaces LuaTeX's line breaking algorithm.

```
function(<node> head, <boolean> is_display)
  return <node> newhead
end
```

The returned node is the head of the list that will be added to the main vertical list, the boolean argument is true if this paragraph is interrupted by a following math display.

If you return something that is not a `<node>`, LuaTeX will apply the internal linebreak algorithm on the list that starts at `<head>`. Otherwise, the `<node>` you return is supposed to be the head of a list of nodes that are all allowed in vertical mode, and at least one of those has to represent an `\hbox`. Failure to do so will result in a fatal error.

Setting this callback to false is possible, but dangerous, because it is possible you will end up in an unfixable 'deadcycles loop'.

10.4.6 `append_to_vlist_filter`

This callback is called whenever LuaTeX adds a box to a vertical list (the `mirrored` argument is obsolete):

```
function(<node> box, <string> locationcode, <number> prevdepth)
  return list [, prevdepth [, checkdepth ] ]
end
```

It is ok to return nothing or `nil` in which case you also need to flush the box or deal with it yourself. The `prevdepth` is also optional. Locations are `box`, `alignment`, `equation`, `equation_number` and `post_linebreak`. When the third argument returned is true the normal `prevdepth` correction will be applied, based on the first node.

10.4.7 `post_linebreak_filter`

This callback is called just after LuaTeX has converted a list of nodes into a stack of `\hboxes`.



```
function(<node> head, <string> groupcode)
    return <node> newhead
end
```

This callback does not replace any internal code.

10.4.8 glyph_run

When set this callback is triggered when T_EX normally handles the ligaturing and kerning. In LuaT_EX you use the `hpack_filter` and `per_linebreak_filter` callbacks for that (where each passes different arguments). This callback doesn't get triggered when there are no glyphs (in LuaT_EX this optimization is controlled by a variable).

```
function(<node> head, <string> groupcode, <number> direction)
    return <node> newhead
end
```

The traditional T_EX font processing is bypassed so you need to take care of that with the helpers. (For the moment we keep the ligaturing and kerning callbacks but they are kind of obsolete.)

10.4.9 hpack_filter

This callback is called when T_EX is ready to start boxing some horizontal mode material. Math items and line boxes are ignored at the moment.

```
function(<node> head, <string> groupcode, <number> size,
        <string> packtype [, <number> direction] [, <node> attributelist])
    return <node> newhead
end
```

The `packtype` is either `additional` or `exactly`. If `additional`, then the `size` is a `\hbox spread ...` argument. If `exactly`, then the `size` is a `\hbox to` In both cases, the number is in scaled points.

This callback does not replace any internal code.

10.4.10 vpack_filter

This callback is called when T_EX is ready to start boxing some vertical mode material. Math displays are ignored at the moment.

This function is very similar to the `hpack_filter`. Besides the fact that it is called at different moments, there is an extra variable that matches T_EX's `\maxdepth` setting.

```
function(<node> head, <string> groupcode, <number> size, <string> packtype,
        <number> maxdepth [, <number> direction] [, <node> attributelist))
    return <node> newhead
end
```



This callback does not replace any internal code.

10.4.11 `hpack_quality`

This callback can be used to intercept the overfull messages that can result from packing a horizontal list (as happens in the par builder). The function takes a few arguments:

```
function(<string> incident, <number> detail, <node> head, <number> first,
        <number> last)
    return <node> whatever
end
```

The incident is one of `overfull`, `underfull`, `loose` or `tight`. The detail is either the amount of overflow in case of `overfull`, or the badness otherwise. The head is the list that is constructed (when protrusion or expansion is enabled, this is an intermediate list). Optionally you can return a node, for instance an overfull rule indicator. That node will be appended to the list (just like \TeX 's own rule would).

10.4.12 `vpack_quality`

This callback can be used to intercept the overfull messages that can result from packing a vertical list (as happens in the page builder). The function takes a few arguments:

```
function(<string> incident, <number> detail, <node> head, <number> first,
        <number> last)
end
```

The incident is one of `overfull`, `underfull`, `loose` or `tight`. The detail is either the amount of overflow in case of `overfull`, or the badness otherwise. The head is the list that is constructed.

10.4.13 `process_rule`

This is an experimental callback. It can be used with rules of subtype 4 (user). The callback gets three arguments: the node, the width and the height. The callback can use `pdf.print` to write code to the pdf file but beware of not messing up the final result. No checking is done.

10.4.14 `pre_output_filter`

This callback is called when \TeX is ready to start boxing the box 255 for `\output`.

```
function(<node> head, <string> groupcode, <number> size, <string> packtype,
        <number> maxdepth [, <number> direction])
    return <node> newhead
end
```

This callback does not replace any internal code.



10.4.15 hyphenate

```
function(<node> head, <node> tail)
end
```

No return values. This callback has to insert discretionary nodes in the node list it receives. Setting this callback to `false` will prevent the internal discretionary insertion pass.

10.4.16 ligaturing

```
function(<node> head, <node> tail)
end
```

No return values. This callback has to apply ligaturing to the node list it receives.

You don't have to worry about return values because the head node that is passed on to the callback is guaranteed not to be a `glyph_node` (if need be, a temporary node will be prepended), and therefore it cannot be affected by the mutations that take place. After the callback, the internal value of the 'tail of the list' will be recalculated.

The next of head is guaranteed to be non-nil.

The next of tail is guaranteed to be nil, and therefore the second callback argument can often be ignored. It is provided for orthogonality, and because it can sometimes be handy when special processing has to take place.

Setting this callback to `false` will prevent the internal ligature creation pass.

You must not ruin the node list. For instance, the head normally is a local par node, and the tail a glue. Messing too much can push LuaTeX into panic mode.

10.4.17 kerning

```
function(<node> head, <node> tail)
end
```

No return values. This callback has to apply kerning between the nodes in the node list it receives. See `ligaturing` for calling conventions.

Setting this callback to `false` will prevent the internal kern insertion pass.

You must not ruin the node list. For instance, the head normally is a local par node, and the tail a glue. Messing too much can push LuaTeX into panic mode.

10.4.18 insert_par

Each paragraph starts with a local par node that keeps track of for instance the direction. You can hook a callback into the creator:

```
function(<node> par, <string> location)
```



end

There is no return value and you should make sure that the node stays valid as otherwise \TeX can get confused.

10.4.19 `mlist_to_hlist`

This callback replaces Lua \TeX 's math list to node list conversion algorithm.

```
function(<node> head, <string> display_type, <boolean> need_penalties)
    return <node> newhead
end
```

The returned node is the head of the list that will be added to the vertical or horizontal list, the string argument is either 'text' or 'display' depending on the current math mode, the boolean argument is true if penalties have to be inserted in this list, false otherwise.

Setting this callback to false is bad, it will almost certainly result in an endless loop.

10.5 Information reporting callbacks

10.5.1 `pre_dump`

```
function()
end
```

This function is called just before dumping to a format file starts. It does not replace any code and there are neither arguments nor return values.

10.5.2 `start_run`

```
function()
end
```

This callback replaces the code that prints Lua \TeX 's banner. Note that for successful use, this callback has to be set in the Lua initialization script, otherwise it will be seen only after the run has already started.

10.5.3 `stop_run`

```
function()
end
```

This callback replaces the code that prints Lua \TeX 's statistics and 'output written to' messages. The engine can still do housekeeping and therefore you should not rely on this hook for post-processing the pdf or log file.



10.5.4 `intercept_tex_error`, `intercept_lua_error`

```
function()  
end
```

This callback is run from inside the $\text{T}_{\text{E}}\text{X}$ error function, and the idea is to allow you to do some extra reporting on top of what $\text{T}_{\text{E}}\text{X}$ already does (none of the normal actions are removed). You may find some of the values in the status table useful. The $\text{T}_{\text{E}}\text{X}$ related callback gets two arguments: the current processing mode and a boolean indicating if there was a runaway.

10.5.5 `show_error_message` and `show_warning_message`

```
function()  
end
```

These callback replaces the code that prints the error message. The usual interaction after the message is not affected.

10.5.6 `start_file`

```
function(category, filename)  
end
```

This callback replaces the code that Lua $\text{T}_{\text{E}}\text{X}$ prints when a file is opened like (`filename` for regular files. The category is a number:

VALUE	MEANING
1	a normal data file, like a $\text{T}_{\text{E}}\text{X}$ source
2	a font map coupling font names to resources
3	an image file (png, pdf, etc)
4	an embedded font subset
5	a fully embedded font

10.5.7 `stop_file`

```
function(category)  
end
```

This callback replaces the code that Lua $\text{T}_{\text{E}}\text{X}$ prints when a file is closed like the `)` for regular files.

10.5.8 `wrapup_run`

This callback is called after the pdf and log files are closed. Use it at your own risk.



10.6 Font-related callbacks

10.6.1 `define_font`

```
function(<string> name, <number> size)
    return <number> id
end
```

The string name is the filename part of the font specification, as given by the user.

The number size is a bit special:

- ▶ If it is positive, it specifies an ‘at size’ in scaled points.
- ▶ If it is negative, its absolute value represents a ‘scaled’ setting relative to the design size of the font.

The font can be defined with `font.define` which returns a font identifier that can be returned in the callback. So, contrary to LuaTeX, in LuaMetaTeX we only accept a number.

The internal structure of the font table that is passed to `font.define` is explained in chapter 6. That table is saved internally, so you can put extra fields in the table for your later Lua code to use. In alternative, `retval` can be a previously defined fontid. This is useful if a previous definition can be reused instead of creating a whole new font structure.

Setting this callback to false is pointless as it will prevent font loading completely but will nevertheless generate errors.

10.6.2 `show_whatsit`

Because we only have a generic `whatsit` it is up to the macro package to provide details when tracing them.

```
function(<node> whatsit, <number> indentation,
        <number> tracinglevel, <number> currentlevel, <number> inputlevel)
    -- no return value
end
```

The indentation tells how many periods are to be typeset if you want to be compatible with the rest of tracing. The tracinglevels indicates if the current level and/or input level are shown cf. `\tracinglevels`. Of course one is free to show whatever in whatever way suits the `whatsit` best.





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11 The T_EX related libraries

11.1 The lua library

11.1.1 Version information

This version of the used Lua interpreter (currently Lua 5.4) can be queried with:

```
<string> v = lua.getversion()
```

The name of used startup file, if at all, is returned by:

```
<string> s = lua.getstartupfile()
```

For this document the reported value is:

```
c:/data/develop/tex-context/tex/texmf-cache/luatex-cache/context/764bd4e1ce0f004ab3cec90018f8b80a/formats/luametatex/cont-en.lui
```

11.1.2 Table allocators

Sometimes performance (and memory usage) can benefit a little from it preallocating a table with `newtable`:

```
<table> t = lua.newtable(100,5000)
```

This preallocates 100 hash entries and 5000 index entries. The `newindex` function create an indexed table with preset values:

```
<table> t = lua.newindex(2500,true)
```

11.1.3 Bytecode registers

Lua registers can be used to store Lua code chunks. The accepted values for assignments are functions and `nil`. Likewise, the retrieved value is either a function or `nil`.

```
lua.bytecode[<number> n] = <function> f  
<function> f = lua.bytecode[<number> n] % -- f()
```

The contents of the `lua.bytecode` array is stored inside the format file as actual Lua bytecode, so it can also be used to preload Lua code. The function must not contain any upvalues. The associated function calls are:

```
lua.setbytecode(<number> n, <function> f)  
<function> f = lua.getbytecode(<number> n)
```



Note: Since a Lua file loaded using `loadfile(filename)` is essentially an anonymous function, a complete file can be stored in a bytecode register like this:

```
lua.setbytecode(n,loadfile(filename))
```

Now all definitions (functions, variables) contained in the file can be created by executing this bytecode register:

```
lua.callbytecode(n)
```

Note that the path of the file is stored in the Lua bytecode to be used in stack backtraces and therefore dumped into the format file if the above code is used in `iniTEX`. If it contains private information, i.e. the user name, this information is then contained in the format file as well. This should be kept in mind when preloading files into a bytecode register in `iniTEX`.

11.1.4 Introspection

The `getstacktop` function return a number indicating how full the Lua stack is. This function only makes sense as breakpoint when checking some mechanism going haywire.

There are four time related helpers. The `getruntime` function returns the time passed since startup. The `getcurrenttime` does what its name says. Just play with them to see how it pays off. The `getpreciseticks` returns a number that can be used later, after a similar call, to get a difference. The `getpreciseseconds` function gets such a tick (delta) as argument and returns the number of seconds. Ticks can differ per operating system, but one always creates a reference first and then deltas to this reference.

11.2 The status library

This contains a number of run-time configuration items that you may find useful in message reporting, as well as an iterator function that gets all of the names and values as a table.

```
<table> info = status.list()
```

The keys in the table are the known items, the value is the current value. There are toplevel items and items that are tables with subentries. The current list is:

TOPLEVEL STATISTICS	
banner	This is LuaMetaTeX, Version 2.09.14
copyright	Taco Hoekwater, Hans Hagen & Wolfgang Schuster
development_id	20210611
filename	luametateX-tex.tex
format_id	580
logfile	luametateX.log
luatex_engine	luametateX
luatex_revision	14
luatex_verbosity	2.09.14
luatex_version	209



permit_loadlib	false
run_state	1
used_compiler	gcc

BUFFERSTATE.*

all	1000000
ini	-1
max	100000000
mem	1000000
min	1000000
ptr	0
set	10000000
stp	1000000
top	810

CALLBACKSTATE.*

bytecode	594
count	195981
direct	93
file	13779
function	53147
local	0
message	0
saved	124832
value	3536

ENGINESTATE.*

banner	This is LuaMetaTeX, Version 2.09.14
copyright	Taco Hoekwater, Hans Hagen & Wolfgang Schuster
development_id	20210611
format_id	580
logfile	luametateX.log
luatex_engine	luametateX
luatex_revision	14
luatex_verbosity	2.09.14
luatex_version	209
permit_loadlib	false
run_state	1
tex_hash_size	131072
used_compiler	gcc

ERRORLINESTATE.*

max	255
min	132



set	250
top	0

ERRORSTATE.*

error	unset
errorcontext	unset
luaerror	unset

EXPANDSTATE.*

max	1000000
min	10000
set	10000
top	10

EXTRASTATE.*

all	0
ini	-1
max	-1
mem	0
min	-1
ptr	0
set	-1
stp	-1
top	0

FILESTATE.*

all	16000
ini	-1
max	2000
mem	500
min	500
ptr	6
set	2000
stp	250
top	12

FONTSTATE.*

all	8595768
ini	-1
max	100000
mem	8595768
min	250
ptr	27
set	100000



stp	250
top	250

HALFERRORLINESTATE.*

max	255
min	80
set	234
top	0

HASHSTATE.*

all	2400000
ini	0
max	2097152
mem	150000
min	150000
ptr	11552
set	250000
stp	100000
top	740032

INPUTSTATE.*

all	320000
ini	-1
max	100000
mem	10000
min	10000
ptr	7
set	100000
stp	10000
top	48

INSERTSTATE.*

all	5760
ini	-1
max	500
mem	240
min	10
ptr	7
set	250
stp	25
top	10

LANGUAGESTATE.*

all	96
ini	0



max	10000
mem	96
min	250
ptr	0
set	250
stp	250
top	250

LOOKUPSTATE.*

all	-1
ini	44320
max	2097152
mem	-1
min	150000
ptr	53913
set	250000
stp	100000
top	131074

LUASTATE.*

bytecodebytes	15920
bytecodes	994
functionsizes	32768
propertyssizes	10000
statebytes	143892345
statebytesmax	152001914

MARKSTATE.*

all	28800
ini	-1
max	10000
mem	1200
min	50
ptr	0
set	250
stp	50
top	50

NESTSTATE.*

all	48000
ini	-1
max	10000
mem	1000
min	1000
ptr	0
set	10000



stp	1000
top	19

NODESTATE.*

all	9000000
ini	0
max	50000000
mem	1000000
min	1000000
ptr	-178659
set	50000000
stp	500000
top	216974

PARAMETERSTATE.*

all	80000
ini	-1
max	100000
mem	20000
min	20000
ptr	1
set	100000
stp	10000
top	49

POOLSTATE.*

all	1050295
ini	836134
max	100000000
mem	1050295
min	10000000
ptr	-1
set	10000000
stp	1000000
top	-1

READSTATE.*

filename	luametateX-tex.tex
iocode	5
linenumber	210
skiplinenumber	163

SAVESTATE.*

all	160000
ini	-1



max	500000
mem	10000
min	100000
ptr	154
set	500000
stp	10000
top	727

SPARSESTATE.*

all	1655512
ini	-1
max	-1
mem	1655512
min	-1
ptr	-1
set	-1
stp	-1
top	-1

STRINGSTATE.*

all	3600000
ini	2141486
max	2097152
mem	150000
min	150000
ptr	53927
set	500000
stp	100000
top	53927

TEXSTATE.*

approximate	36960231
-------------	----------

TOKENSTATE.*

all	8000000
ini	488230
max	10000000
mem	1000000
min	1000000
ptr	1229786
set	10000000
stp	250000
top	678733



WARNINGSTATE.*

warning	unset
warningtag	unset

There are also getters for the subtables. The whole repertoire of functions in the status table is: `getbufferstate`, `getcallbackstate`, `getconstants`, `geterrorlinestate`, `geterrorstate`, `getexpandstate`, `getextrastate`, `getfilestate`, `getfontstate`, `gethalferrorlinestate`, `gethashstate`, `getinputstate`, `getinsertstate`, `getlanguagesstate`, `getlookupstate`, `getluastate`, `getmarkstate`, `getneststate`, `getnodestate`, `getparameterstate`, `getpoolstate`, `getreadstate`, `getsavestate`, `getsparsestate`, `getstringstate`, `gettexstate`, `gettokenstate`, `getwarningstate`, `iocodes`, `list`, `resetmessages`. The error and warning messages can be wiped with the `resetmessages` function. The states in subtables relate to memory management and are mostly there for development purposes.

The `getconstants` query gives back a table with all kind of internal quantities and again these are only relevant for diagnostic and development purposes. Many are good old \TeX constants that are describes in the original documentation of the source but some are definitely `LuaMeta \TeX` specific.

CONSTANTS.*

<code>awful_bad</code>	1073741823
<code>decent_criterium</code>	12
<code>default_catcode_table</code>	-1
<code>default_deadcycles</code>	25
<code>default_eqno_gap_step</code>	1000
<code>default_hangafter</code>	1
<code>default_output_box</code>	255
<code>default_pre_display_gap</code>	2000
<code>default_rule</code>	26214
<code>default_space_factor</code>	1000
<code>default_tolerance</code>	10000
<code>deplorable</code>	100000
<code>eject_penalty</code>	-10000
<code>ignore_depth</code>	-65536000
<code>infinite_bad</code>	10000
<code>infinite_penalty</code>	10000
<code>infinity</code>	2147483647
<code>large_width_excess</code>	7230584
<code>loose_criterium</code>	99
<code>max_bytecode_index</code>	65535
<code>max_cardinal</code>	-1
<code>max_category_code</code>	15
<code>max_char_code</code>	15
<code>max_character_code</code>	1114111
<code>max_data_value</code>	2097151
<code>max_dimen</code>	1073741823



max_function_reference	2097151
max_half_value	32767
max_halfword	1073741823
max_integer	2147483647
max_mark_index	9999
max_math_class_code	7
max_math_family_index	255
max_n_of_bytecodes	65536
max_n_of_catcode_tables	256
max_n_of_fonts	100000
max_n_of_languages	10000
max_n_of_marks	10000
max_n_of_math_families	256
max_n_of_registers	65536
max_newline_character	127
max_quarterword	65535
max_register_index	65535
max_size_of_word	1024
max_space_factor	32767
min_cardinal	0
min_data_value	0
min_dimen	-1073741823
min_halfword	-1073741823
min_infinity	-2147483647
min_integer	-2147483647
min_quarterword	0
min_space_factor	0
no_catcode_table	-2
null	0
null_flag	-1073741824
null_font	0
one_bp	65781
preset_rule_thickness	1073741824
small_stretchability	1663497
tex_eqtb_size	590032
tex_hash_prime	131041
tex_hash_size	131072
two	131072
unity	65536
unused_attribute_value	-2147483647
unused_script_value	0
unused_state_value	0
zero_glue	0

Most variables speak for themselves, some are more obscure. For instance the `run_state` variable indicates what the engine is doing:



N	meaning	explanation
0	initializing	--ini mnode
1	updating	relates to \overloadmode
2	production	a regular (format driven) run

11.3 The tex library

11.3.1 Introduction

The tex table contains a large list of virtual internal T_EX parameters that are partially writable. The designation ‘virtual’ means that these items are not properly defined in Lua, but are only frontends that are handled by a metatable that operates on the actual T_EX values. As a result, most of the Lua table operators (like pairs and #) do not work on such items.

At the moment, it is possible to access almost every parameter that you can use after \the, is a single token or is sort of special in T_EX. This excludes parameters that need extra arguments, like \the\scriptfont. The subset comprising simple integer and dimension registers are writable as well as readable (like \tracingcommands and \parindent).

11.3.2 Internal parameter values, set and get

For all the parameters in this section, it is possible to access them directly using their names as index in the tex table, or by using one of the functions tex.get and tex.set.

The exact parameters and return values differ depending on the actual parameter, and so does whether tex.set has any effect. For the parameters that *can* be set, it is possible to use global as the first argument to tex.set; this makes the assignment global instead of local.

```
tex.set (["global",] <string> n, ...)
... = tex.get (<string> n)
```

Glue is kind of special because there are five values involved. The return value is a glue_spec node but when you pass false as last argument to tex.get you get the width of the glue and when you pass true you get all five values. Otherwise you get a node which is a copy of the internal value so you are responsible for its freeing at the Lua end. When you set a glue quantity you can either pass a glue_spec or upto five numbers.

Beware: as with regular Lua tables you can add values to the tex table. So, the following is valid:

```
tex.foo = 123
```

When you access a T_EX parameter a look up takes place. For read-only variables that means that you will get something back, but when you set them you create a new entry in the table thereby making the original invisible.

There are a few special cases that we make an exception for: prevdepth, prevgraf and spacefactor. These normally are accessed via the tex.nest table:



```
tex.nest[tex.nest.ptr].prevdepth = p
tex.nest[tex.nest.ptr].spacefactor = s
```

However, the following also works:

```
tex.prevdepth = p
tex.spacefactor = s
```

Keep in mind that when you mess with node lists directly at the Lua end you might need to update the top of the nesting stack's `prevdepth` explicitly as there is no way LuaTeX can guess your intentions. By using the accessor in the `tex` tables, you get and set the values at the top of the nesting stack.

11.3.2.1 Integer parameters

The integer parameters accept and return Lua integers. In some cases the values are checked, trigger other settings or result in some immediate change of behaviour: `adjdemerits`, `adjustspacing`, `adjustspacingshrink`, `adjustspacingstep`, `adjustspacingstretch`, `automatichyphenpenalty`, `automigrationmode`, `binoppenalty`, `brokenpenalty`, `catcodetable`, `clubpenalty`, `day`, `defaultshyphenchar`, `defaultskewchar`, `delimitfactor`, `displaywidowpenalty`, `doublehyphendemerits`, `endlinechar`, `errorcontextlines`, `escapechar`, `exceptionpenalty`, `exhyphenchar`, `exhyphenpenalty`, `explicitshyphenpenalty`, `fam`, `finalhyphendemerits`, `firstvalidlanguage`, `floatingpenalty`, `globaldefs`, `glyphdatafield`, `glyphoptions`, `glyphscale`, `glyphscriptfield`, `glyphscriptscale`, `glyphscriptscriptscale`, `glyphstatefield`, `glyphtextscale`, `glyphxscale`, `glyphyscale`, `hangafter`, `hbadness`, `holdinginserts`, `hyphenationmode`, `hyphenpenalty`, `interlinepenalty`, `language`, `lastlinefit`, `lefthyphenmin`, `linedirection`, `linepenalty`, `localbrokenpenalty`, `localinterlinepenalty`, `looseness`, `luacopyinputnodes`, `mathdelimitersmode`, `mathdirection`, `mathdisplayskipmode`, `matheqno-gapstep`, `mathflattenmode`, `mathitalicsmode`, `mathnolimitsmode`, `mathpenaltiesmode`, `mathrulesfam`, `mathrulesmode`, `mathrulethicknessmode`, `mathscriptboxmode`, `mathscriptcharmode`, `mathscriptsmode`, `mathsurroundmode`, `maxdeadcycles`, `month`, `newlinechar`, `normalizelinemode`, `nospaces`, `outputbox`, `outputpenalty`, `overloadmode`, `pardirection`, `pausing`, `postdisplaypenalty`, `prebinoppenalty`, `predisplaydirection`, `predisplaygapfactor`, `predisplaypenalty`, `prerelpenalty`, `pretolerance`, `protrudechars`, `relpenalty`, `rightshyphenmin`, `savinghyphcodes`, `savingvdiscards`, `setfontid`, `setlanguage`, `showboxbreadth`, `showboxdepth`, `shownodedetails`, `supmarkmode`, `textdirection`, `time`, `tolerance`, `tracingalignments`, `tracingassigns`, `tracingcommands`, `tracingfonts`, `tracinggroups`, `tracinghyphenation`, `tracingifs`, `tracinglevels`, `tracinglostchars`, `tracingmacros`, `tracingmath`, `tracingnesting`, `tracingonline`, `tracingoutput`, `tracingpages`, `tracingparagraphs`, `tracingrestores`, `tracingstats`, `uchyph`, `vbadness`, `widowpenalty`, `year`.

Some integer parameters are read only, because they are actually referring not to some internal integer register but to an engine property: `deadcycles`, `insertpenalties`, `parshape`, `interlinepenalties`, `clubpenalties`, `widowpenalties`, `displaywidowpenalties`, `prevgraf` and `spacefactor`.

11.3.2.2 Dimension parameters

The dimension parameters accept Lua numbers (signifying scaled points) or strings (with in-



cluded dimension). The result is always a number in scaled points. These are read-write: `box-maxdepth`, `delimitershortfall`, `displayindent`, `displaywidth`, `emergencystretch`, `glyphx-offset`, `glyphyoffset`, `hangindent`, `hfuzz`, `hsize`, `lineskiplimit`, `mathsurround`, `maxdepth`, `nulldelimiterspace`, `overfullrule`, `parindent`, `preplaysize`, `pxdimen`, `scriptspace`, `splitmaxdepth`, `vfuzz`, `vsize`.

These are read-only: `pagedepth`, `pagefilllstretch`, `pagefillstretch`, `pagefilstretch`, `pagegoal`, `pageshrink`, `pagestretch` and `pagetotal`.

11.3.2.3 Direction parameters

The direction states can be queried with: `gettexdir`, `getlinedir`, `getmathdir` and `getpardir`. You can set them with `settextdir`, `setlinedir`, `setmathdir` and `setpardir`, commands that accept a number. You can also set these parameters as table key/values: `textdirection`, `linedirection`, `mathdirection` and `pardirection`, so the next code sets the text direction to `r2l`:

```
tex.textdirection = 1
```

11.3.2.4 Glue parameters

The internal glue parameters accept and return a userdata object that represents a `glue_spec` node: `abovedisplayshortskip`, `abovedisplayskip`, `baselineskip`, `belowdisplayshortskip`, `belowdisplayskip`, `leftskip`, `lineskip`, `mathsurroundskip`, `parfillleftskip`, `parfillskip`, `parskip`, `rightskip`, `spaceskip`, `splittopskip`, `tabskip`, `topskip`, `xspaceskip`.

11.3.2.5 Muglue parameters

All muglue parameters are to be used read-only and return a Lua string `medmuskip`, `thickmuskip`, `thinmuskip`.

11.3.2.6 Tokenlist parameters

The tokenlist parameters accept and return Lua strings. Lua strings are converted to and from token lists using `\the \toks` style expansion: all category codes are either space (10) or other (12). It follows that assigning to some of these, like `'tex.output'`, is actually useless, but it feels bad to make exceptions in view of a coming extension that will accept full-blown token strings. Here is the lot: `errhelp`, `everycr`, `everydisplay`, `everyeof`, `everyhbox`, `everyjob`, `everymath`, `everypar`, `everytab`, `everyvbox`, `output`.

11.3.3 Convert commands

All 'convert' commands are read-only and return a Lua string. The supported commands at this moment are: `Uchar`, `csstring`, `directlua`, `expanded`, `fontname`, `fontspecifiedname`, `formatname`, `jobname`, `luabytecode`, `luaescapestring`, `luafunction`, `luatexbanner`, `meaning`, `meaningfull`, `meaningless`, `number`, `romannumeral`, `string`, `todimension`, `tointeger`, `toscaled`. You will get an error message if an operation is not (yet) permitted. Some take an string or number argument, just like at the \TeX end some extra input is expected.



11.3.4 Item commands

All so called ‘item’ commands are read-only and return a number. The complete list of these commands is: `Umathcharclass`, `Umathcharfam`, `Umathcharslot`, `badness`, `currentgrouplevel`, `currentgrouptype`, `currentifbranch`, `currentiflevel`, `currentifttype`, `dimexpr`, `fontchardp`, `fontcharht`, `fontcharic`, `fontcharwd`, `fontid`, `fontspecifiedsize`, `glueexpr`, `glueshrink`, `glueshrinkorder`, `gluestretch`, `gluestretchorder`, `gluetomu`, `inputlineno`, `insertprogress`, `lastarguments`, `lastchkdir`, `lastchknum`, `lastkern`, `lastnodesubtype`, `lastnodetype`, `lastpenalty`, `lastskip`, `leftmarginkern`, `luatexrevision`, `luatexversion`, `mathscale`, `mathstyle`, `muexpr`, `mutoglu`, `numericsscale`, `numexpr`, `overshoot`, `parametercount`, `parshapedimen`, `parshapeindent`, `parshapelength`, `rightmarginkern`. No all are currently supported but eventually that might be the case. Like the lists in previous sections, there are differences between Lua \TeX and LuaMeta \TeX , where some commands are organized differently in order to provide a consistent Lua interface.

11.3.5 Accessing registers: `set*`, `get*` and `is*`

\TeX 's attributes (`\attribute`), counters (`\count`), dimensions (`\dimen`), skips (`\skip`, `\muskip`) and token (`\toks`) registers can be accessed and written to using two times five virtual sub-tables of the `tex` table:

<code>tex.attribute</code>	<code>tex.skip</code>	<code>tex.muglu</code>
<code>tex.count</code>	<code>tex.glue</code>	<code>tex.toks</code>
<code>tex.dimen</code>	<code>tex.muskip</code>	

It is possible to use the names of relevant `\attributedef`, `\countdef`, `\dimendef`, `\skipdef`, or `\toksdef` control sequences as indices to these tables:

```
tex.count.scratchcounter = 0
enormous = tex.dimen['maxdimen']
```

In this case, Lua \TeX looks up the value for you on the fly. You have to use a valid `\countdef` (or `\attributedef`, or `\dimendef`, or `\skipdef`, or `\toksdef`), anything else will generate an error (the intent is to eventually also allow `<chardef tokens>` and even macros that expand into a number).

- ▶ The count registers accept and return Lua numbers.
- ▶ The dimension registers accept Lua numbers (in scaled points) or strings (with an included absolute dimension; `em` and `ex` and `px` are forbidden). The result is always a number in scaled points.
- ▶ The token registers accept and return Lua strings. Lua strings are converted to and from token lists using `\the \toks` style expansion: all category codes are either space (10) or other (12).
- ▶ The skip registers accept and return `glue_spec` userdata node objects (see the description of the node interface elsewhere in this manual).
- ▶ The glue registers are just skip registers but instead of userdata are verbose.



- ▶ Like the counts, the attribute registers accept and return Lua numbers.

As an alternative to array addressing, there are also accessor functions defined for all cases, for example, here is the set of possibilities for `\skip` registers:

```
tex.setskip (["global",] <number> n, <node> s)
tex.setskip (["global",] <string> s, <node> s)
<node> s = tex.getskip (<number> n)
<node> s = tex.getskip (<string> s)
```

We have similar setters for `count`, `dimen`, `muskip`, and `toks`. Counters and `dimen` are represented by numbers, `skips` and `muskip`s by nodes, and `toks` by strings.

Again the glue variants are not using the `glue-spec` userdata nodes. The `setglue` function accepts upto five arguments: `width`, `stretch`, `shrink`, `stretch order` and `shrink order`. Non-numeric values set the property to zero. The `getglue` function reports all five properties, unless the second argument is `false` in which case only the `width` is returned.

Here is an example using a threesome:

```
local d = tex.getdimen("foo")
if tex.isdimen("oof") then
    tex.setdimen("oof",d)
end
```

There are six extra `skip` (glue) related helpers:

```
tex.setglue (["global"], <number> n,
            width, stretch, shrink, stretch_order, shrink_order)
tex.setglue (["global"], <string> s,
            width, stretch, shrink, stretch_order, shrink_order)
width, stretch, shrink, stretch_order, shrink_order =
    tex.getglue (<number> n)
width, stretch, shrink, stretch_order, shrink_order =
    tex.getglue (<string> s)
```

The other two are `tex.setmuglue` and `tex.getmuglue`.

There are such helpers for `dimen`, `count`, `skip`, `muskip`, `box` and attribute registers but the glue ones are special because they have to deal with more properties.

As with the general `get` and `set` function discussed before, for the `skip` registers `getskip` returns a node and `getglue` returns numbers, while `setskip` accepts a node and `setglue` expects upto 5 numbers. Again, when you pass `false` as second argument to `getglue` you only get the `width` returned. The same is true for the `mu` variants `getmuskip`, `setmuskip`, `getmuskip` and `setmuskip`.

For tokens registers we have an alternative where a catcode table is specified:

```
tex.scantoks(0,3,"$e=mc^2$")
tex.scantoks("global",0,3,"$\int\limits^1_2$")
```



In the function-based interface, it is possible to define values globally by using the string `global` as the first function argument.

There is a dedicated getter for marks: `getmark` that takes two arguments. The first argument is one of `top`, `bottom`, `first`, `splitbottom` or `splitfirst`, and the second argument is a marks class number. When no arguments are given the current maximum number of classes is returned.

When `tex.gettoks` gets an extra argument `true` it will return a table with userdata tokens.

11.3.6 Character code registers: `[get|set]*code[s]`

T_EX's character code tables (`\lccode`, `\uccode`, `\sfcode`, `\catcode`, `\mathcode`, `\delcode`) can be accessed and written to using six virtual subtables of the `tex` table

<code>tex.lccode</code>	<code>tex.sfcode</code>	<code>tex.mathcode</code>
<code>tex.uccode</code>	<code>tex.catcode</code>	<code>tex.delcode</code>

The function call interfaces are roughly as above, but there are a few twists. `sfcodes` are the simple ones:

```
tex.setsfcode (["global",] <number> n, <number> s)
<number> s = tex.getsfcode (<number> n)
```

The function call interface for `lccode` and `uccode` additionally allows you to set the associated sibling at the same time:

```
tex.setlccode (["global"], <number> n, <number> lc)
tex.setlccode (["global"], <number> n, <number> lc, <number> uc)
<number> lc = tex.getlccode (<number> n)
tex.setuccode (["global"], <number> n, <number> uc)
tex.setuccode (["global"], <number> n, <number> uc, <number> lc)
<number> uc = tex.getuccode (<number> n)
```

The function call interface for `catcode` also allows you to specify a category table to use on assignment or on query (default in both cases is the current one):

```
tex.setcatcode (["global"], <number> n, <number> c)
tex.setcatcode (["global"], <number> cattable, <number> n, <number> c)
<number> lc = tex.getcatcode (<number> n)
<number> lc = tex.getcatcode (<number> cattable, <number> n)
```

The interfaces for `delcode` and `mathcode` use small array tables to set and retrieve values:

```
tex.setmathcode (["global"], <number> n, <table> mval )
<table> mval = tex.getmathcode (<number> n)
tex.setdelcode (["global"], <number> n, <table> dval )
<table> dval = tex.getdelcode (<number> n)
```



Where the table for `mathcode` is an array of 3 numbers, like this:

```
{
  <number> class,
  <number> family,
  <number> character
}
```

And the table for `delcode` is an array with 4 numbers, like this:

```
{
  <number> small_fam,
  <number> small_char,
  <number> large_fam,
  <number> large_char
}
```

You can also avoid the table:

```
tex.setmathcode (["global"], <number> n, <number> class,
  <number> family, <number> character)
class, family, char =
  tex.getmathcodes (<number> n)
tex.setdelcode (["global"], <number> n, <number> smallfam,
  <number> smallchar, <number> largefam, <number> largechar)
smallfam, smallchar, largefam, largechar =
  tex.getdelcodes (<number> n)
```

Normally, the third and fourth values in a delimiter code assignment will be zero according to `\Udelcode` usage, but the returned table can have values there (if the delimiter code was set using `\delcode`, for example). Unset `delcode`'s can be recognized because `dval[1]` is `-1`.

11.3.7 Box registers: `[get|set]box`

It is possible to set and query actual boxes, coming for instance from `\hbox`, `\vbox` or `\vtop`, using the node interface as defined in the node library:

```
tex.box
```

for array access, or

```
tex.setbox(["global",] <number> n, <node> s)
tex.setbox(["global",] <string> cs, <node> s)
<node> n = tex.getbox(<number> n)
<node> n = tex.getbox(<string> cs)
```

for function-based access. In the function-based interface, it is possible to define values globally by using the string `global` as the first function argument.



Be warned that an assignment like

```
tex.box[0] = tex.box[2]
```

does not copy the node list, it just duplicates a node pointer. If `\box2` will be cleared by \TeX commands later on, the contents of `\box0` becomes invalid as well. To prevent this from happening, always use `node.copy_list` unless you are assigning to a temporary variable:

```
tex.box[0] = node.copy_list(tex.box[2])
```

11.3.8 triggerbuildpage

You should not expect too much from the `triggerbuildpage` helpers because often \TeX doesn't do much if it thinks nothing has to be done, but it might be useful for some applications. It just does as it says it calls the internal function that build a page, given that there is something to build.

11.3.9 splitbox

You can split a box:

```
local vlist = tex.splitbox(n,height,mode)
```

The remainder is kept in the original box and a packaged `vlist` is returned. This operation is comparable to the `\vsplit` operation. The mode can be `additional` or `exactly` and concerns the split off box.

11.3.10 Accessing math parameters: [get|set]math

It is possible to set and query the internal math parameters using:

```
tex.setmath(["global",] <string> n, <string> t, <number> n)
<number> n = tex.getmath(<string> n, <string> t)
```

As before an optional first parameter `global` indicates a global assignment.

The first string is the parameter name minus the leading 'Umath', and the second string is the style name minus the trailing 'style'. Just to be complete, the values for the math parameter name are:

<code>quad</code>	<code>axis</code>	<code>operatorsize</code>
<code>overbarkern</code>	<code>overbarrule</code>	<code>overbarvgap</code>
<code>underbarkern</code>	<code>underbarrule</code>	<code>underbarvgap</code>
<code>radicalkern</code>	<code>radicalrule</code>	<code>radicalvgap</code>
<code>radicaldegreebefore</code>	<code>radicaldegreeafter</code>	<code>radicaldegreeraise</code>
<code>stackvgap</code>	<code>stacknumup</code>	<code>stackdenomdown</code>
<code>fractionrule</code>	<code>fractionnumvgap</code>	<code>fractionnumup</code>
<code>fractiondenomvgap</code>	<code>fractiondenomdown</code>	<code>fractiondelsize</code>



limitabovevgap	limitabovebgap	limitabovekern	
limitbelowvgap	limitbelowbgap	limitbelowkern	
underdelimitervgap	underdelimiterbgap		
overdelimitervgap	overdelimiterbgap		
subshiftdrop	supshiftdrop	subshiftdown	
subsupshiftdown	subtopmax	supshiftdown	
supbottommin	supsubbottommax	subsupvgap	
spaceafterscript	connectoroverlapmin		
ordordspacing	ordopspacing	ordbinspacing	ordrelspacing
ordopenspacing	ordclosespacing	ordpunctspacing	ordinnerspacing
opordspacing	opopspacing	opbinspacing	oprelspacing
opopenspacing	opclorespacing	oppunctspacing	opinnerspacing
binordspacing	binopspacing	binbinspacing	binrelspacing
binopenspacing	binclorespacing	binpunctspacing	bininnerspacing
relordspacing	rellorespacing	relbinspacing	relrelspacing
relopenspacing	relclorespacing	relpunctspacing	relinnerspacing
openordspacing	openopspacing	openbinspacing	openrelspacing
openopenspacing	openclorespacing	openpunctspacing	openinnerspacing
closeordspacing	closeopspacing	closebinspacing	closerelspacing
closeopenspacing	closeclorespacing	closepunctspacing	closeinnerspacing
punctordspacing	punctopspacing	punctbinspacing	punctrelspacing
punctopenspacing	punctclorespacing	punctpunctspacing	punctinnerspacing
innerordspacing	inneropspacing	innerbinspacing	innerrelspacing
inneropenspacing	innerclorespacing	innerpunctspacing	innerinnerspacing

The values for the style parameter are:

display	crampeddisplay
text	crampedtext
script	crampedscript
scriptscript	crampedscriptscript

The value is either a number (representing a dimension or number) or a glue spec node representing a muskip for `ordordspacing` and similar spacing parameters.

11.3.11 Special list heads: `[get|set]list`

The virtual table `tex.lists` contains the set of internal registers that keep track of building page lists.

FIELD	EXPLANATION
<code>page_ins_head</code>	circular list of pending insertions
<code>contribute_head</code>	the recent contributions
<code>page_head</code>	the current page content
<code>hold_head</code>	used for held-over items for next page
<code>adjust_head</code>	head of the current <code>\adjust</code> list
<code>pre_adjust_head</code>	head of the current <code>\adjust pre</code> list



`page_discards_head` head of the discarded items of a page break
`split_discards_head` head of the discarded items in a vsplit

The getter and setter functions are `getlist` and `setlist`. You have to be careful with what you set as T_EX can have expectations with regards to how a list is constructed or in what state it is.

11.3.12 Semantic nest levels: `getnest` and `ptr`

The virtual table `nest` contains the currently active semantic nesting state. It has two main parts: a zero-based array of userdata for the semantic nest itself, and the numerical value `ptr`, which gives the highest available index. Neither the array items in `nest[]` nor `ptr` can be assigned to (as this would confuse the typesetting engine beyond repair), but you can assign to the individual values inside the array items, e.g. `tex.nest[tex.nest.ptr].prevdepth`.

`tex.nest[tex.nest.ptr]` is the current nest state, `nest[0]` the outermost (main vertical list) level. The getter function is `getnest`. You can pass a number (which gives you a list), nothing or `top`, which returns the topmost list, or the string `ptr` which gives you the index of the topmost list.

The known fields are:

KEY	TYPE	MODES	EXPLANATION
<code>mode</code>	number	all	the meaning of these numbers depends on the engine and sometimes even the version; you can use <code>tex.getmodevalues()</code> to get the mapping: positive values signal vertical, horizontal and math mode, while negative values indicate inner and inline variants
<code>modeline</code>	number	all	source input line where this mode was entered in, negative inside the output routine
<code>head</code>	node	all	the head of the current list
<code>tail</code>	node	all	the tail of the current list
<code>prevgraf</code>	number	vmode	number of lines in the previous paragraph
<code>prevdepth</code>	number	vmode	depth of the previous paragraph
<code>spacefactor</code>	number	hmode	the current space factor
<code>direction</code>	node	hmode	stack used for temporary storage by the line break algorithm
<code>noad</code>	node	mmode	used for temporary storage of a pending fraction numerator, for <code>\over</code> etc.
<code>delimptr</code>	node	mmode	used for temporary storage of the previous math delimiter, for <code>\middle</code>
<code>mathdir</code>	boolean	mmode	true when during math processing the <code>\mathdir</code> is not the same as the surrounding <code>\textdir</code>
<code>mathstyle</code>	number	mmode	the current <code>\mathstyle</code>

When a second string argument is given to the `getnest`, the value with that name is returned. Of course the level must be valid. When `setnest` gets a third argument that value is assigned to the field given as second argument.



11.3.13 Print functions

The `tex` table also contains the three print functions that are the major interface from Lua scripting to \TeX . The arguments to these three functions are all stored in an in-memory virtual file that is fed to the \TeX scanner as the result of the expansion of `\directlua`.

The total amount of returnable text from a `\directlua` command is only limited by available system ram. However, each separate printed string has to fit completely in \TeX 's input buffer. The result of using these functions from inside callbacks is undefined at the moment.

11.3.13.1 `print`

```
tex.print(<string> s, ...)  
tex.print(<number> n, <string> s, ...)  
tex.print(<table> t)  
tex.print(<number> n, <table> t)
```

Each string argument is treated by \TeX as a separate input line. If there is a table argument instead of a list of strings, this has to be a consecutive array of strings to print (the first non-string value will stop the printing process).

The optional parameter can be used to print the strings using the catcode regime defined by `\catcodetable n`. If `n` is `-1`, the currently active catcode regime is used. If `n` is `-2`, the resulting catcodes are the result of `\the \toks`: all category codes are 12 (other) except for the space character, that has category code 10 (space). Otherwise, if `n` is not a valid catcode table, then it is ignored, and the currently active catcode regime is used instead.

The very last string of the very last `tex.print` command in a `\directlua` will not have the `\endlinechar` appended, all others do.

11.3.13.2 `sprint`

```
tex.sprint(<string> s, ...)  
tex.sprint(<number> n, <string> s, ...)  
tex.sprint(<table> t)  
tex.sprint(<number> n, <table> t)
```

Each string argument is treated by \TeX as a special kind of input line that makes it suitable for use as a partial line input mechanism:

- ▶ \TeX does not switch to the ‘new line’ state, so that leading spaces are not ignored.
- ▶ No `\endlinechar` is inserted.
- ▶ Trailing spaces are not removed. Note that this does not prevent \TeX itself from eating spaces as result of interpreting the line. For example, in

```
before\directlua{tex.sprint("\relax")tex.sprint(" in between")}after
```

the space before `in between` will be gobbled as a result of the ‘normal’ scanning of `\relax`.

If there is a table argument instead of a list of strings, this has to be a consecutive array of strings to print (the first non-string value will stop the printing process).



The optional argument sets the catcode regime, as with `tex.print`. This influences the string arguments (or numbers turned into strings).

Although this needs to be used with care, you can also pass token or node userdata objects. These get injected into the stream. Tokens had best be valid tokens, while nodes need to be around when they get injected. Therefore it is important to realize the following:

- ▶ When you inject a token, you need to pass a valid token userdata object. This object will be collected by Lua when it no longer is referenced. When it gets printed to \TeX the token itself gets copied so there is no interference with the Lua garbage collection. You manage the object yourself. Because tokens are actually just numbers, there is no real extra overhead at the \TeX end.
- ▶ When you inject a node, you need to pass a valid node userdata object. The node related to the object will not be collected by Lua when it no longer is referenced. It lives on at the \TeX end in its own memory space. When it gets printed to \TeX the node reference is used assuming that node stays around. There is no Lua garbage collection involved. Again, you manage the object yourself. The node itself is freed when \TeX is done with it.

If you consider the last remark you might realize that we have a problem when a printed mix of strings, tokens and nodes is reused. Inside \TeX the sequence becomes a linked list of input buffers. So, "123" or "\foo{123}" gets read and parsed on the fly, while `<token userdata>` already is tokenized and effectively is a token list now. A `<node userdata>` is also tokenized into a token list but it has a reference to a real node. Normally this goes fine. But now assume that you store the whole lot in a macro: in that case the tokenized node can be flushed many times. But, after the first such flush the node is used and its memory freed. You can prevent this by using copies which is controlled by setting `\luacopyinputnodes` to a non-zero value. This is one of these fuzzy areas you have to live with if you really mess with these low level issues.

11.3.13.3 `tprint`

```
tex.tprint({<number> n, <string> s, ...}, {...})
```

This function is basically a shortcut for repeated calls to `tex.sprint(<number> n, <string> s, ...)`, once for each of the supplied argument tables.

11.3.13.4 `cprint`

This function takes a number indicating the to be used catcode, plus either a table of strings or an argument list of strings that will be pushed into the input stream.

```
tex.cprint( 1," 1: ${\\foo}") tex.print("\\par") -- a lot of \bgroup s
tex.cprint( 2," 2: ${\\foo}") tex.print("\\par") -- matching \egroup s
tex.cprint( 9," 9: ${\\foo}") tex.print("\\par") -- all get ignored
tex.cprint(10,"10: ${\\foo}") tex.print("\\par") -- all become spaces
tex.cprint(11,"11: ${\\foo}") tex.print("\\par") -- letters
tex.cprint(12,"12: ${\\foo}") tex.print("\\par") -- other characters
tex.cprint(14,"12: ${\\foo}") tex.print("\\par") -- comment triggers
```



11.3.13.5 write

```
tex.write(<string> s, ...)  
tex.write(<table> t)
```

Each string argument is treated by T_EX as a special kind of input line that makes it suitable for use as a quick way to dump information:

- ▶ All catcodes on that line are either ‘space’ (for ‘ ’) or ‘character’ (for all others).
- ▶ There is no `\endlinechar` appended.

If there is a table argument instead of a list of strings, this has to be a consecutive array of strings to print (the first non-string value will stop the printing process).

11.3.14 Helper functions

11.3.14.1 round

```
<number> n = tex.round(<number> o)
```

Rounds Lua number `o`, and returns a number that is in the range of a valid T_EX register value. If the number starts out of range, it generates a ‘number too big’ error as well.

11.3.14.2 scale

```
<number> n = tex.scale(<number> o, <number> delta)  
<table> n = tex.scale(table o, <number> delta)
```

Multiplies the Lua numbers `o` and `delta`, and returns a rounded number that is in the range of a valid T_EX register value. In the table version, it creates a copy of the table with all numeric top-level values scaled in that manner. If the multiplied number(s) are of range, it generates ‘number too big’ error(s) as well.

Note: the precision of the output of this function will depend on your computer's architecture and operating system, so use with care! An interface to LuaT_EX's internal, 100% portable scale function will be added at a later date.

11.3.14.3 number and romannumeral

These are the companions to the primitives `\number` and `\romannumeral`. They can be used like:

```
tex.print(tex.romannumeral(123))
```

11.3.14.4 fontidentifier and fontname

The first one returns the name only, the second one reports the size too.

```
tex.print(tex.fontname(tex.fontname))  
tex.print(tex.fontname(tex.fontidier))
```



11.3.14.5 `sp`

```
<number> n = tex.sp(<number> o)
<number> n = tex.sp(<string> s)
```

Converts the number `o` or a string `s` that represents an explicit dimension into an integer number of scaled points.

For parsing the string, the same scanning and conversion rules are used that LuaTeX would use if it was scanning a dimension specifier in its TeX-like input language (this includes generating errors for bad values), expect for the following:

1. only explicit values are allowed, control sequences are not handled
2. infinite dimension units (`fil...`) are forbidden
3. `mu` units do not generate an error (but may not be useful either)

11.3.14.6 `tex.getlinenumber` and `tex.setlinenumber`

You can mess with the current line number:

```
local n = tex.getlinenumber()
tex.setlinenumber(n+10)
```

which can be shortcut to:

```
tex.setlinenumber(10,true)
```

This might be handy when you have a callback that reads numbers from a file and combines them in one line (in which case an error message probably has to refer to the original line). Interference with TeX's internal handling of numbers is of course possible.

11.3.14.7 `error`, `show_context` and `gethelptext`

```
tex.error(<string> s)
tex.error(<string> s, <table> help)
<string> s = tex.gethelptext()
```

This creates an error somewhat like the combination of `\errhelp` and `\errmessage` would. During this error, deletions are disabled.

The array part of the help table has to contain strings, one for each line of error help.

In case of an error the `show_context` function will show the current context where we're at (in the expansion).

11.3.14.8 `getfamilyoffont`

When you pass a proper family identifier the next helper will return the font currently associated with it.

```
<integer> id = font.getfamilyoffont(<integer> fam)
```



11.3.14.9 [set|get]interaction

The engine can be in one of four modes:

VALUE	mode	MEANING
0	batch	omits all stops and omits terminal output
1	nonstop	omits all stops
2	scroll	omits error stops
3	errorstop	stops at every opportunity to interact

The mode can be queried and set with:

```
<integer> i = tex.getinteraction()
tex.setinteraction(<integer> i)
```

11.3.14.10 runtoks and quittoks

Because of the fact that \TeX is in a complex dance of expanding, dealing with fonts, typesetting paragraphs, messing around with boxes, building pages, and so on, you cannot easily run a nested \TeX run (read nested main loop). However, there is an option to force a local run with `runtoks`. The content of the given token list register gets expanded locally after which we return to where we triggered this expansion, at the Lua end. Instead a function can get passed that does some work. You have to make sure that at the end \TeX is in a sane state and this is not always trivial. A more complex mechanism would complicate \TeX itself (and probably also harm performance) so this simple local expansion loop has to do.

```
tex.runtoks(<token register>)
tex.runtoks(<lua function>)
tex.runtoks(<macro name>)
tex.runtoks(<register name>)
```

When the `\tracingnesting` parameter is set to a value larger than 2 some information is reported about the state of the local loop. The return value indicates an error:

VALUE	meaning
0	no error
1	bad register number
2	unknown macro or register name
3	macro is unsuitable for runtoks (has arguments)

This function has two optional arguments in case a token register is passed:

```
tex.runtoks(<token register>, force, grouped, obeymode)
```

Inside for instance an `\edef` the `runtoks` function behaves (at least tries to) like it were an `\the`. This prevents unwanted side effects: normally in such a definition tokens remain tokens and (for instance) characters don't become nodes. With the second argument you can force the local main loop, no matter what. The third argument adds a level of grouping. The last argument



tells the scanner to stay in the current mode.

You can quit the local loop with `\endlocalcontrol` or from the Lua end with `tex.quittoks`. In that case you end one level up! Of course in the end that can mean that you arrive at the main level in which case an extra end will trigger a redundancy warning (not an abort!).

11.3.14.11 `forcehmode`

An example of a (possible error triggering) complication is that \TeX expects to be in some state, say horizontal mode, and you have to make sure it is when you start feeding back something from Lua into \TeX . Normally a user will not run into issues but when you start writing tokens or nodes or have a nested run there can be situations that you need to run `forcehmode`. There is no recipe for this and intercepting possible cases would weaken Lua \TeX 's flexibility.

11.3.14.12 `hashtokens`

```
for i,v in pairs (tex.hashtokens()) do ... end
```

Returns a list of names. This can be useful for debugging, but note that this also reports control sequences that may be unreachable at this moment due to local redefinitions: it is strictly a dump of the hash table. You can use `token.create` to inspect properties, for instance when the command key in a created table equals 123, you have the `cmdname` value `undefined_cs`.

11.3.14.13 `definefont`

```
tex.definefont(<string> csname, <number> fontid)  
tex.definefont(<boolean> global, <string> csname, <number> fontid)
```

Associates `csname` with the internal font number `fontid`. The definition is global if (and only if) `global` is specified and true (the setting of `globaldefs` is not taken into account).

11.3.15 Functions for dealing with primitives

11.3.15.1 `enableprimitives`

```
tex.enableprimitives(<string> prefix, <table> primitive names)
```

This function accepts a prefix string and an array of primitive names. For each combination of 'prefix' and 'name', the `tex.enableprimitives` first verifies that 'name' is an actual primitive (it must be returned by one of the `tex.extraprimitives` calls explained below, or part of \TeX 82, or `\directlua`). If it is not, `tex.enableprimitives` does nothing and skips to the next pair.

But if it is, then it will construct a `csname` variable by concatenating the 'prefix' and 'name', unless the 'prefix' is already the actual prefix of 'name'. In the latter case, it will discard the 'prefix', and just use 'name'.

Then it will check for the existence of the constructed `csname`. If the `csname` is currently undefined (note: that is not the same as `\relax`), it will globally define the `csname` to have the meaning: run code belonging to the primitive 'name'. If for some reason the `csname` is already defined, it does nothing and tries the next pair.



ifx ignorespaces indent input inputlineno insert insertpenalties inter-
 linepenalty jobname kern language lastbox lastkern lastpenalty lastskip lc-
 code leaders left lefthyphenmin leftskip leqno let limits linepenalty line-
 skip lineskiplimit long looseness lower lowercase mark mathaccent mathbin
 mathchar mathchardef mathchoice mathclose mathcode mathinner mathop math-
 open mathord mathpunct mathrel mathsurround maxdeadcycles maxdepth mean-
 ing meaningfull meaningless medmuskip message middle mkern month moveleft
 moveright mskip multiply muskip muskipdef newlinechar noalign noexpand noin-
 dent nolimits nonscript nonstopmode nulldelimiterspace nullfont number omit
 or ordlimits outer output outputpenalty over overfullrule overline overshoot
 overwithdelims pagedepth pagefilllstretch pagefillstretch pagefilstretch
 pagegoal pageshrink pagestretch pagetotal par parfillleftskip parfillskip
 parindent parshape parskip patterns pausing penalty postdisplaypenalty pre-
 displaypenalty predisplaysize pretolerance prevdepth prevgraf radical raise
 relax relpenalty right righthyphenmin rightskip romannumeral scaledfontdi-
 men scriptfont scriptscriptfont scriptscriptstyle scriptspace scriptstyle
 scrollmode setbox setlanguage sfcodes shipout show showbox showboxbreadth
 showboxdepth showlists shownodedetails showthe skewchar skip skipdef space-
 factor spaceskip span splitbotmark splitfirstmark splitmaxdepth splittop-
 skip string tabskip textfont textstyle the thickmuskip thinmuskip time todi-
 mension tointeger toks toksdef tolerance topmark topskip toscaled tracing-
 commands tracinglostchars tracingmacros tracingonline tracingoutput trac-
 ingpages tracingparagraphs tracingrestores tracingstats uccode uchyph un-
 derline unhbox unhcopy unhpick unkern unpenalty unskip unvbox unvcopy un-
 vpack uppercase vadjust valign vbadness vbox vcenter vfil vfill vfilneg vfuzz
 vrule vsize vskip vsplit vss vtop wd widowpenalty xdef xleaders xspaceskip
 year

core

etex

botmarks clubpenalties currentgrouplevel currentgrouptype currentifbranch
 currentiflevel currentifttype detokenize dimexpr displaywidowpenalties
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 glueshrink glueshrinkorder gluestretch gluestretchorder gluetomu ifc-
 sname ifdefined iffontchar interactionmode interlinepenalties lastchkdim
 lastchknum lastlinefit lastnodetype marks muexpr mutogluen numericsscale nu-
 mexpr pagediscards parshapedimen parshapeindent parshapelength predisplay-
 direction protected savinghyphcodes savingvdiscards scantokens showgroups
 showifs showtokens splitbotmarks splitdiscards splitfirstmarks topmarks
 tracingalignments tracingassigns tracinggroups tracingifs tracinglevels
 tracingnesting unexpanded unless widowpenalties

luatex

UUskewed UUskewedwithdelims Uabove Uabovewithdelims Uatop Uatopwithdelims
 Uchar Udelcode Udelcodenum Udelimiter Udelimiterover Udelimiterunder Uhex-
 tensible Uleft Umathaccent Umathaccentbaseheight Umathaccentvariant Umath-
 adapttoleft Umathadapttright Umathaxis Umathbinbinspacing Umathbinclos-
 espacing Umathbininnerspacing Umathbinopenspacing Umathbinopspacing Umath-
 binordspacing Umathbinpunctspacing Umathbinrelspacing Umathbotaccentvari-
 ant Umathchar Umathcharclass Umathchardef Umathcharfam Umathcharnum Umath-



charnumdef Umathcharslot Umathclass Umathclosebinspacing Umathcloseclos-
 espacing Umathcloseinnerspacing Umathcloseopenspacing Umathcloseopspacing
 Umathcloseordspacing Umathclosepunctspacing Umathcloserelspacing Umath-
 code Umathcodenum Umathconnectoroverlapmin Umathdegreeariant Umathde-
 limiterovervariant Umathdelimiterundervariant Umathdenominatorvariant
 Umathfractiondelsize Umathfractiondenomdown Umathfractiondenomvgap Umath-
 fractionnumup Umathfractionnumvgap Umathfractionrule Umathfractionvari-
 ant Umathhextensiblevariant Umathinnerbinspacing Umathinnerclosespacing
 Umathinnerinnerspacing Umathinneropenspacing Umathinneropspacing Umathin-
 nerordspacing Umathinnerpunctspacing Umathinnerrelspacing Umathlimitabove-
 bgap Umathlimitabovekern Umathlimitabovevgap Umathlimitbelowbgap Umath-
 limitbelowkern Umathlimitbelowvgap Umathlimits Umathnoaxis Umathnolimits
 Umathnolimitsubfactor Umathnolimitsupfactor Umathnumeratorvariant Umathop-
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 ing Umathordrelspacing Umathoverbarkern Umathoverbarrule Umathoverbarv-
 gap Umathoverdelimiterbgap Umathoverdelimitervariant Umathoverdelimiter-
 vgap Umathoverlayaccentvariant Umathoverlinevariant Umathphantom Umath-
 punctbinspacing Umathpunctclosespacing Umathpunctinnerspacing Umathpunc-
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 luafunction luafunctioncall luatexbanner luatexrevision luatexversion math-
 delimitersmode mathdirection mathdisplayskipmode matheqnogapstep math-
 flattenmode mathitalicsmode mathnolimitsmode mathpenaltiesmode mathrules-
 fam mathrulesmode mathrulethicknessmode mathscale mathscriptboxmode math-
 scriptcharmode mathscriptsmode mathstyle mathsurroundmode mathsurround-
 skip mugluespecdef mutable noaligned noboundary nohrule norelax normalize-
 linemode nospaces novrule orelse orunless outputbox overloaded overloadmode
 parametercount parattr pardirection permanent postexhyphenchar posthyphen-
 char prebinoppenalty predisplayskipfactor preexhyphenchar prehyphenchar pre-
 relpenalty protrudechars protrusionboundary pxdimen quitvmode rightmargin-
 kern rpcode savecatcodetable scantextokens setfontid snapshotpar supmark-
 mode swapcsvalues textdirection thewithoutunit thewithproperty tokenized
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 xtoksapp xtokspre

Note that `luatex` does not contain `directlua`, as that is considered to be a core primitive, along with all the \TeX 82 primitives, so it is part of the list that is returned from `'core'`.

Running `tex.extraprimitives` will give you the complete list of primitives -ini startup. It is exactly equivalent to `tex.extraprimitives("etex", "luatex")`.



11.3.15.3 primitives

```
<table> t = tex.primitives()
```

This function returns a list of all primitives that Lua \TeX knows about.

11.3.16 Core functionality interfaces

11.3.16.1 badness

```
<number> b = tex.badness(<number> t, <number> s)
```

This helper function is useful during linebreak calculations. t and s are scaled values; the function returns the badness for when total t is supposed to be made from amounts that sum to s . The returned number is a reasonable approximation of $100(t/s)^3$;

11.3.16.2 tex.resetparagraph

This function resets the parameters that \TeX normally resets when a new paragraph is seen.

11.3.16.3 linebreak

```
local <node> nodelist, <table> info =  
  tex.linebreak(<node> listhead, <table> parameters)
```

The understood parameters are as follows:

NAME	TYPE	EXPLANATION
<code>pardir</code>	string	
<code>pretolerance</code>	number	
<code>tracingparagraphs</code>	number	
<code>tolerance</code>	number	
<code>looseness</code>	number	
<code>hyphenpenalty</code>	number	
<code>exhyphenpenalty</code>	number	
<code>pdfadjustspacing</code>	number	
<code>adjdemerits</code>	number	
<code>protrudechars</code>	number	
<code>linepenalty</code>	number	
<code>lastlinefit</code>	number	
<code>doublehyphendemerits</code>	number	
<code>finalhyphendemerits</code>	number	
<code>hangafter</code>	number	
<code>interlinepenalty</code>	number or table	if a table, then it is an array like <code>\interlinepenalties</code>
<code>clubpenalty</code>	number or table	if a table, then it is an array like <code>\clubpenalties</code>
<code>widowpenalty</code>	number or table	if a table, then it is an array like <code>\widowpenalties</code>
<code>brokenpenalty</code>	number	



<code>emergencystretch</code>	number	in scaled points
<code>hangindent</code>	number	in scaled points
<code>hsize</code>	number	in scaled points
<code>leftskip</code>	glue_spec node	
<code>rightskip</code>	glue_spec node	
<code>parshape</code>	table	

Note that there is no interface for `\displaywidowpenalties`, you have to pass the right choice for `widowpenalties` yourself.

It is your own job to make sure that `listhead` is a proper paragraph list: this function does not add any nodes to it. To be exact, if you want to replace the core line breaking, you may have to do the following (when you are not actually working in the `pre_linebreak_filter` or `linebreak_filter` callbacks, or when the original list starting at `listhead` was generated in horizontal mode):

- ▶ add an ‘indent box’ and perhaps a `par` node at the start (only if you need them)
- ▶ replace any found final glue by an infinite penalty (or add such a penalty, if the last node is not a glue)
- ▶ add a glue node for the `\parfillskip` after that penalty node
- ▶ make sure all the `prev` pointers are OK

The result is a node list, it still needs to be `vpacked` if you want to assign it to a `\vbox`. The returned info table contains four values that are all numbers:

NAME	EXPLANATION
<code>prevdepth</code>	depth of the last line in the broken paragraph
<code>prevgraf</code>	number of lines in the broken paragraph
<code>looseness</code>	the actual looseness value in the broken paragraph
<code>demerits</code>	the total demerits of the chosen solution

Note there are a few things you cannot interface using this function: You cannot influence font expansion other than via `pdfadjustspacing`, because the settings for that take place elsewhere. The same is true for `hbadness` and `hfuzz` etc. All these are in the `hpack` routine, and that fetches its own variables via `globals`.

11.3.16.4 `shipout`

```
tex.shipout(<number> n)
```

Ships out box number `n` to the output file, and clears the box register.

11.3.16.5 `getpagestate`

This helper reports the current page state: `empty`, `box_``there` or `inserts_``only` as integer value.

11.3.16.6 `getlocallevel`

This integer reports the current level of the local loop. It's only useful for debugging and the



(relative state) numbers can change with the implementation.

11.3.17 Functions related to `synctex`

The next helpers only make sense when you implement your own `synctex` logic. Keep in mind that the library used in editors assumes a certain logic and is geared for plain and \LaTeX , so after a decade users expect a certain behaviour.

NAME	EXPLANATION
<code>setsynctexmode</code>	0 is the default and used normal <code>synctex</code> logic, 1 uses the values set by the next helpers while 2 also sets these for glyph nodes; 3 sets glyphs and glue and 4 sets only glyphs
<code>setsynctextag</code>	set the current tag (file) value (obeys save stack)
<code>setsynctexline</code>	set the current line value (obeys save stack)
<code>setsynctexnofiles</code>	disable <code>synctex</code> file logging
<code>getsynctexmode</code>	returns the current mode (for values see above)
<code>getsynctextag</code>	get the currently set value of tag (file)
<code>getsynctexline</code>	get the currently set value of line
<code>forcesynctextag</code>	overload the tag (file) value (0 resets)
<code>forcesynctexline</code>	overload the line value (0 resets)

The last one is somewhat special. Due to the way files are registered in `SyncTeX` we need to explicitly disable that feature if we provide our own alternative if we want to avoid that overhead. Passing a value of 1 disables registering.

11.4 The `texconfig` table

This is a table that is created empty. A startup Lua script could fill this table with a number of settings that are read out by the executable after loading and executing the startup file. Watch out: some keys are different from `LuaTeX`, which is a side effect of a more granular and dynamic memory management.

KEY	TYPE	DEFAULT	COMMENT
<code>bufferize</code>	number/table	1000000	input buffer bytes
<code>filesize</code>	number/table	1000	max number of open files
<code>fontsize</code>	number/table	250	number of permitted fonts
<code>hashsize</code>	number/table	150000	number of hash entries
<code>inputsize</code>	number/table	10000	maximum input stack
<code>languagesize</code>	number/table	250	number of permitted languages
<code>marksize</code>	number/table	50	number of mark classes
<code>nestsize</code>	number/table	1000	max depth of nesting
<code>nodesize</code>	number/table	1000000	max node memory (various size)
<code>parametersize</code>	number/table	20000	max size of parameter stack
<code>poolsize</code>	number/table	10000000	max number of string bytes
<code>savesize</code>	number/table	100000	mas size of save stack



stringsize	number/table	150000	max number of strings
tokensize	number/table	1000000	max token memory
expandsize	number/table	10000	max expansion nesting
propertyssize	number	0	initial size of node properties table
functionsize	number	0	initial size of Lua functions table
errorlinesize	number	79	how much or an error is shown
halferrorlinesize	number	50	idem
formatname	string		
jobname	string		

If no format name or jobname is given on the command line, the related keys will be tested first instead of simply quitting. The statistics library has methods for tracking down how much memory is available and has been configured. The size parameters take a number (for the maximum allocated size) or a table with three possible keys: `size`, `plus` (for extra size) and `step` for the increment when more memory is needed. They all start out with a hard coded minimum and also have an hard coded maximum, the the configured size sits somewhere between these.

11.5 The texio library

This library takes care of the low-level I/O interface: writing to the log file and/or console.

11.5.1 write and writeselector

```
texio.write(<string> target, <string> s, ...)
texio.write(<string> s, ...)
texio.writeselector(<string> s, ...)
```

Without the target argument, writes all given strings to the same location(s) \TeX writes messages to at this moment. If `\batchmode` is in effect, it writes only to the log, otherwise it writes to the log and the terminal. The optional target can be one of `terminal`, `logfile` or `terminal_and_logfile`.

Note: If several strings are given, and if the first of these strings is or might be one of the targets above, the target must be specified explicitly to prevent Lua from interpreting the first string as the target.

11.5.2 writenl and writeselectornl

```
texio.writenl(<string> target, <string> s, ...)
texio.writenl(<string> s, ...)
texio.writeselectornl(<string> target, ...)
```

This function behaves like `texio.write`, but makes sure that the given strings will appear at the beginning of a new line. You can pass a single empty string if you only want to move to the next line.



The selector variants always expect a selector, so there is no misunderstanding if logfile is a string or selector.

11.5.3 setescape

You can disable ^^ escaping of control characters by passing a value of zero.

11.5.4 closeinput

This function should be used with care. It acts as `\endinput` but at the Lua end. You can use it to (sort of) force a jump back to `TEX`. Normally a Lua call will just collect prints and at the end bump an input level and flush these prints. This function can help you stay at the current level but you need to know what you're doing (or more precise: what `TEX` is doing with input).

11.6 The token library

11.6.1 The scanner

The token library provides means to intercept the input and deal with it at the Lua level. The library provides a basic scanner infrastructure that can be used to write macros that accept a wide range of arguments. This interface is on purpose kept general and as performance is quite okay so one can build additional parsers without too much overhead. It's up to macro package writers to see how they can benefit from this as the main principle behind `LuaTEX` is to provide a minimal set of tools and no solutions. The scanner functions are probably the most intriguing.

FUNCTION	ARGUMENT	RESULT
<code>scankeyword</code>	string	returns true if the given keyword is gobbled; as with the regular <code>T_EX</code> keyword scanner this is case insensitive (and ascii based)
<code>scankeywordcs</code>	string	returns true if the given keyword is gobbled; this variant is case sensitive and also suitable for utf8
<code>scanint</code>		returns an integer
<code>scanreal</code>		returns a number from e.g. 1, 1.1, .1 with optional collapsed signs
<code>scanfloat</code>		returns a number from e.g. 1, 1.1, .1, 1.1E10, , .1e-10 with optional collapsed signs
<code>scandimen</code>	infinity, mu-units	returns a number representing a dimension or two numbers being the filler and order
<code>scanglue</code>	mu-units	returns a glue spec node
<code>scantoks</code>	definer, expand	returns a table of tokens
<code>scancode</code>	bitset	returns a character if its category is in the given bitset (representing catcodes)
<code>scanstring</code>		returns a string given between <code>{}</code> , as <code>\macro</code> or as sequence of characters with catcode 11 or 12



scanargument	this one is similar to scanstring but also accepts a <code>\cs</code> (which then get expanded)
scanword	returns a sequence of characters with catcode 11 or 12 as string
scancsname	returns <code>foo</code> after scanning <code>\foo</code>
scanlist	picks up a box specification and returns a <code>[h v]list</code> node

The integer, dimension and glue scanners take an extra optional argument that signals that an optional equal is permitted.

The scanners can be considered stable apart from the one scanning for a token. The `scancode` function takes an optional number, the `scankeyword` function a normal Lua string. The `infinity` boolean signals that we also permit `fill` as dimension and the `mu-units` flags the scanner that we expect math units. When scanning tokens we can indicate that we are defining a macro, in which case the result will also provide information about what arguments are expected and in the result this is separated from the meaning by a separator token. The `expand` flag determines if the list will be expanded.

The `scanargument` function expands the given argument. When a braced argument is scanned, expansion can be prohibited by passing `false` (default is `true`). In case of a control sequence passing `false` will result in a one-level expansion (the meaning of the macro).

The string scanner scans for something between curly braces and expands on the way, or when it sees a control sequence it will return its meaning. Otherwise it will scan characters with catcode `letter` or `other`. So, given the following definition:

```
\def\oof{oof}
\def\foo{foo-\oof}
```

we get:

NAME	RESULT	
<code>\directlua{token.scanstring()}{foo}</code>	<code>foo</code>	full expansion
<code>\directlua{token.scanstring()}foo</code>	<code>foo</code>	letters and others
<code>\directlua{token.scanstring()}\foo</code>	<code>foo-oof</code>	meaning

The `\foo` case only gives the meaning, but one can pass an already expanded definition (`\edef'd`). In the case of the braced variant one can of course use the `\detokenize` and `\unexpanded` primitives since there we do expand.

The `scanword` scanner can be used to implement for instance a number scanner. An optional boolean argument can signal that a trailing space or `\relax` should be gobbled:

```
function token.scannumber(base)
    return tonumber(token.scanword(),base)
end
```

This scanner accepts any valid Lua number so it is a way to pick up floats in the input.

You can use the Lua interface as follows:



```

\directlua {
  function mymacro(n)
    ...
  end
}

\def\mymacro#1{%
  \directlua {
    mymacro(\number\dimexpr#1)
  }%
}

```

```

\mymacro{12pt}
\mymacro{\dimen0}

```

You can also do this:

```

\directlua {
  function mymacro()
    local d = token.scandimen()
    ...
  end
}

\def\mymacro{%
  \directlua {
    mymacro()
  }%
}

```

```

\mymacro 12pt
\mymacro \dimen0

```

It is quite clear from looking at the code what the first method needs as argument(s). For the second method you need to look at the Lua code to see what gets picked up. Instead of passing from T_EX to Lua we let Lua fetch from the input stream.

In the first case the input is tokenized and then turned into a string, then it is passed to Lua where it gets interpreted. In the second case only a function call gets interpreted but then the input is picked up by explicitly calling the scanner functions. These return proper Lua variables so no further conversion has to be done. This is more efficient but in practice (given what T_EX has to do) this effect should not be overestimated. For numbers and dimensions it saves a bit but for passing strings conversion to and from tokens has to be done anyway (although we can probably speed up the process in later versions if needed).



11.6.2 Picking up one token

The scanners look for a sequence. When you want to pick up one token from the input you use `scannext`. This creates a token with the (low level) properties as discussed next. This token is just the next one. If you want to enforce expansion first you can use `scantoken` or the `_expanded` variants. Internally tokens are characterized by a number that packs a lot of information. In order to access the bits of information a token is wrapped in a `userdata` object.

The `expand` function will trigger expansion of the next token in the input. This can be quite unpredictable but when you call it you probably know enough about \TeX not to be too worried about that. It basically is a call to the internal `expand` related function.

NAME	EXPLANATION
<code>scannext</code>	get the next token
<code>scannextexpanded</code>	get the next expanded token
<code>skipnext</code>	skip the next token
<code>skipnextexpanded</code>	skip the next expanded token
<code>peeknext</code>	get the next token and put it back in the input
<code>peeknextexpanded</code>	get the next expanded token and put it back in the input

The `peek` function accept a boolean argument that triggers skipping spaces and alike.

11.6.3 Creating tokens

The creator function can be used as follows:

```
local t = token.create("relax")
```

This gives back a token object that has the properties of the `\relax` primitive. The possible properties of tokens are:

NAME	EXPLANATION
<code>command</code>	a number representing the internal command number
<code>cmdname</code>	the type of the command (for instance the <code>catcode</code> in case of a character or the classifier that determines the internal treatment)
<code>csname</code>	the associated control sequence (if applicable)
<code>id</code>	the unique id of the token
<code>tok</code>	the full token number as stored in \TeX
<code>active</code>	a boolean indicating the active state of the token
<code>expandable</code>	a boolean indicating if the token (macro) is expandable
<code>protected</code>	a boolean indicating if the token (macro) is protected
<code>frozen</code>	a boolean indicating if the token is a frozen command
<code>user</code>	a boolean indicating if the token is a user defined command
<code>index</code>	a number that indicated the subcommand; differs per command

Alternatively you can use a getter `get<fieldname>` to access a property of a token.

The numbers that represent a `catcode` are the same as in \TeX itself, so using this information



assumes that you know a bit about T_EX's internals. The other numbers and names are used consistently but are not frozen. So, when you use them for comparing you can best query a known primitive or character first to see the values.

You can ask for a list of commands:

```
local t = token.commands()
```

The id of a token class can be queried as follows:

```
local id = token.command_id("math_shift")
```

If you really know what you're doing you can create character tokens by not passing a string but a number:

```
local letter_x = token.create(string.byte("x"))
local other_x = token.create(string.byte("x"), 12)
```

Passing weird numbers can give side effects so don't expect too much help with that. As said, you need to know what you're doing. The best way to explore the way these internals work is to just look at how primitives or macros or `\chardef`'d commands are tokenized. Just create a known one and inspect its fields. A variant that ignores the current catcode table is:

```
local whatever = token.new(123, 12)
```

You can test if a control sequence is defined with `is_defined`, which accepts a string and returns a boolean:

```
local okay = token.is_defined("foo")
```

The largest character possible is returned by `biggest_char`, just in case you need to know that boundary condition.

11.6.4 Macros

The `set_macro` function can get upto 4 arguments:

```
set_macro("csname", "content")
set_macro("csname", "content", "global")
set_macro("csname")
```

You can pass a catcodetable identifier as first argument:

```
set_macro(catcodetable, "csname", "content")
set_macro(catcodetable, "csname", "content", "global")
set_macro(catcodetable, "csname")
```

The results are like:

```
\def\csname{content}
```



```
\gdef\csname{content}
\def\csname{}
```

The `getmacro` function can be used to get the content of a macro while the `getmeaning` function gives the meaning including the argument specification (as usual in \TeX separated by `->`).

The `set_char` function can be used to do a `\chardef` at the Lua end, where invalid assignments are silently ignored:

```
set_char("csname",number)
set_char("csname",number,"global")
```

A special one is the following:

```
set_lua("mycode",id)
set_lua("mycode",id,"global","protected")
```

This creates a token that refers to a Lua function with an entry in the table that you can access with `lua.getfunctions_table`. It is the companion to `\luadef`. When the first (and only) argument is true the size will preset to the value of `texconfig.function_size`.

The `pushmacro` and `popmacro` function are very experimental and can be used to get and set an existing macro. The `push` call returns a user data object and the `pop` takes such a userdata object. These object have no accessors and are to be seen as abstractions.

11.6.5 Pushing back

There is a (for now) experimental putter:

```
local t1 = token.scannext()
local t2 = token.scannext()
local t3 = token.scannext()
local t4 = token.scannext()
-- watch out, we flush in sequence
token.putnext { t1, t2 }
-- but this one gets pushed in front
token.putnext ( t3, t4 )
```

When we scan `wxyz!` we get `yzwx!` back. The argument is either a table with tokens or a list of tokens. The `token.expand` function will trigger expansion but what happens really depends on what you're doing where.

This putter is actually a bit more flexible because the following input also works out okay:

```
\def\foo#1{[#1]}

\directlua {
  local list = { 101, 102, 103, token.create("foo"), "{abracadabra}" }
  token.putnext("(the)")
  token.putnext(list)
```



```

token.putnext("(order)")
token.putnext(unpack(list))
token.putnext("(is reversed)")
}

```

We get this:

```
(is reversed)efg[abracadabra](order)efg[abracadabra](the)
```

So, strings get converted to individual tokens according to the current catcode regime and numbers become characters also according to this regime.

11.6.6 Nota bene

When scanning for the next token you need to keep in mind that we're not scanning like T_EX does: expanding, changing modes and doing things as it goes. When we scan with Lua we just pick up tokens. Say that we have:

```
\oof
```

but `\oof` is undefined. Normally T_EX will then issue an error message. However, when we have:

```
\def\foo{\oof}
```

We get no error, unless we expand `\foo` while `\oof` is still undefined. What happens is that as soon as T_EX sees an undefined macro it will create a hash entry and when later it gets defined that entry will be reused. So, `\oof` really exists but can be in an undefined state.

```

oof : oof
foo : foo
myfirstoof :

```

This was entered as:

```

oof      : \directlua{tex.print(token.scancsname())}\oof
foo      : \directlua{tex.print(token.scancsname())}\foo
myfirstoof : \directlua{tex.print(token.scancsname())}\myfirstoof

```

The reason that you see `oof` reported and not `myfirstoof` is that `\oof` was already used in a previous paragraph.

If we now say:

```
\def\foo{}
```

we get:

```

oof : oof
foo : foo
myfirstoof :

```



And if we say

```
\def\foo{\oof}
```

we get:

```
oof : oof  
foo : foo  
myfirstoof :
```

When scanning from Lua we are not in a mode that defines (undefined) macros at all. There we just get the real primitive undefined macro token.

```
670119 537472498  
675898 536969024  
670565 536985953
```

This was generated with:

```
\directlua{local t = token.scannext() tex.print(t.id.." "..t.tok)}\myfirstoof  
\directlua{local t = token.scannext() tex.print(t.id.." "..t.tok)}\mysecondoof  
\directlua{local t = token.scannext() tex.print(t.id.." "..t.tok)}\mythirdoof
```

So, we do get a unique token because after all we need some kind of Lua object that can be used and garbage collected, but it is basically the same one, representing an undefined control sequence.



12 The MetaPost library `mplib`

12.1 Process management

The MetaPost library interface registers itself in the table `mplib`. It is based on `mplib` version 3.10.

Not all functionality is described here. Once we're out of the experimental stage some more information will be added.

12.1.1 `new`

To create a new MetaPost instance, call

```
<mpinstance> mp = mplib.new({...})
```

This creates the `mp` instance object. The argument is a hash table that can have a number of different fields, as follows:

NAME	TYPE	DESCRIPTION	DEFAULT
<code>error_line</code>	number	error line width	79
<code>print_line</code>	number	line length in ps output	100
<code>random_seed</code>	number	the initial random seed	variable
<code>math_mode</code>	string	the number system to use: scaled, double or decimal	scaled
<code>interaction</code>	string	the interaction mode: batch, nonstop, scroll or errorstop	errorstop
<code>job_name</code>	string	a compatibility value	
<code>find_file</code>	function	a function to find files	only local files
<code>utf8_mode</code>	boolean	permit characters in the range 128 upto 255 to be part of names	false
<code>text_mode</code>	boolean	permit characters 2 and 3 as fencing string literals	false

The binary mode is no longer available in the LuaTeX version of `mplib`. It offers no real advantage and brings a ton of extra libraries with platform specific properties that we can now avoid. We might introduce a high resolution scaled variant at some point but only when it pays of performance wise.

The `find_file` function should be of this form:

```
<string> found = finder (<string> name, <string> mode, <string> type)
```

with:



NAME	THE REQUESTED FILE
mode	the file mode: r or w
type	the kind of file, one of: mp, tfm, map, pfb, enc

Return either the full path name of the found file, or nil if the file cannot be found.

Note that the new version of mplib no longer uses binary mem files, so the way to preload a set of macros is simply to start off with an input command in the first execute call.

When you are processing a snippet of text starting with `btex` or `verbatimtex` and ending with `etex`, the MetaPost `texscriptmode` parameter controls how spaces and newlines get honoured. The default value is 1. Possible values are:

NAME	MEANING
0	no newlines
1	newlines in <code>verbatimtex</code>
2	newlines in <code>verbatimtex</code> and <code>etex</code>
3	no leading and trailing strip in <code>verbatimtex</code>
4	no leading and trailing strip in <code>verbatimtex</code> and <code>btex</code>

That way the Lua handler (assigned to `make_text`) can do what it likes. An `etex` has to be followed by a space or `;` or be at the end of a line and preceded by a space or at the beginning of a line.

12.1.2 statistics

You can request statistics with:

```
<table> stats = mp:statistics()
```

This function returns the vital statistics for an mplib instance. There are four fields, giving the maximum number of used items in each of four allocated object classes:

FIELD	TYPE	EXPLANATION
main_memory	number	memory size
hash_size	number	hash size
param_size	number	simultaneous macro parameters
max_in_open	number	input file nesting levels

Note that in the new version of mplib, this is informational only. The objects are all allocated dynamically, so there is no chance of running out of space unless the available system memory is exhausted.

12.1.3 execute

You can ask the MetaPost interpreter to run a chunk of code by calling

```
<table> rettable = execute(mp, "metapost code")
```



for various bits of MetaPost language input. Be sure to check the `rettable.status` (see below) because when a fatal MetaPost error occurs the `mplib` instance will become unusable thereafter.

Generally speaking, it is best to keep your chunks small, but beware that all chunks have to obey proper syntax, like each of them is a small file. For instance, you cannot split a single statement over multiple chunks.

In contrast with the normal stand alone `mpost` command, there is *no* implied 'input' at the start of the first chunk.

12.1.4 finish

```
<table> rettable = finish(mp)
```

If for some reason you want to stop using an `mplib` instance while processing is not yet actually done, you can call `finish`. Eventually, used memory will be freed and open files will be closed by the Lua garbage collector, but an explicit `finish` is the only way to capture the final part of the output streams.

12.2 The end result

The return value of `execute` and `finish` is a table with a few possible keys (only `status` is always guaranteed to be present).

FIELD	TYPE	EXPLANATION
<code>log</code>	string	output to the 'log' stream
<code>term</code>	string	output to the 'term' stream
<code>error</code>	string	output to the 'error' stream (only used for 'out of memory')
<code>status</code>	number	the return value: 0 = good, 1 = warning, 2 = errors, 3 = fatal error
<code>fig</code>	table	an array of generated figures (if any)

When `status` equals 3, you should stop using this `mplib` instance immediately, it is no longer capable of processing input.

If it is present, each of the entries in the `fig` array is a userdata representing a figure object, and each of those has a number of object methods you can call:

FIELD	TYPE	EXPLANATION
<code>boundingbox</code>	function	returns the bounding box, as an array of 4 values
<code>postscript</code>	function	returns a string that is the ps output of the <code>fig</code> . this function accepts two optional integer arguments for specifying the values of prologues (first argument) and <code>procset</code> (second argument)
<code>svg</code>	function	returns a string that is the svg output of the <code>fig</code> . This function accepts an optional integer argument for specifying the value of prologues
<code>objects</code>	function	returns the actual array of graphic objects in this <code>fig</code>
<code>filename</code>	function	the filename this <code>fig</code> 's PostScript output would have written to in stand alone mode
<code>width</code>	function	the <code>fontcharwd</code> value



height	function	the fontcharht value
depth	function	the fontchardp value
italic	function	the fontcharit value
charcode	function	the (rounded) charcode value

Note: you can call `fig:objects()` only once for any one `fig` object!

When the boundingbox represents a 'negated rectangle', i.e. when the first set of coordinates is larger than the second set, the picture is empty.

Graphical objects come in various types: `fill`, `outline`, `text`, `start_clip`, `stop_clip`, `start_bounds`, `stop_bounds`, `special`. Each type has a different list of accessible values.

There is a helper function (`mplib.fields(obj)`) to get the list of accessible values for a particular object, but you can just as easily use the tables given below.

All graphical objects have a field type that gives the object type as a string value; it is not explicit mentioned in the following tables. In the following, numbers are PostScript points represented as a floating point number, unless stated otherwise. Field values that are of type table are explained in the next section.

12.2.1 fill

FIELD	TYPE	EXPLANATION
path	table	the list of knots
htap	table	the list of knots for the reversed trajectory
pen	table	knots of the pen
color	table	the object's color
linejoin	number	line join style (bare number)
miterlimit	number	miterlimit
prescript	string	the prescript text
postscript	string	the postscript text

The entries `htap` and `pen` are optional.

12.2.2 outline

FIELD	TYPE	EXPLANATION
path	table	the list of knots
pen	table	knots of the pen
color	table	the object's color
linejoin	number	line join style (bare number)
miterlimit	number	miterlimit
linecap	number	line cap style (bare number)
dash	table	representation of a dash list
prescript	string	the prescript text
postscript	string	the postscript text



The entry dash is optional.

12.2.3 text

FIELD	TYPE	EXPLANATION
text	string	the text
font	string	font tfm name
dsize	number	font size
color	table	the object's color
width	number	
height	number	
depth	number	
transform	table	a text transformation
prescript	string	the prescript text
postscript	string	the postscript text

12.2.4 special

FIELD	TYPE	EXPLANATION
prescript	string	special text

12.2.5 start_bounds, start_clip

FIELD	TYPE	EXPLANATION
path	table	the list of knots

12.2.5.1 stop_bounds, stop_clip

Here are no fields available.

12.3 Subsidiary table formats

12.3.1 Paths and pens

Paths and pens (that are really just a special type of paths as far as mplib is concerned) are represented by an array where each entry is a table that represents a knot.

FIELD	TYPE	EXPLANATION
left_type	string	when present: endpoint, but usually absent
right_type	string	like left_type
x_coord	number	X coordinate of this knot
y_coord	number	Y coordinate of this knot
left_x	number	X coordinate of the precontrol point of this knot



<code>left_y</code>	number	Y coordinate of the precontrol point of this knot
<code>right_x</code>	number	X coordinate of the postcontrol point of this knot
<code>right_y</code>	number	Y coordinate of the postcontrol point of this knot

There is one special case: pens that are (possibly transformed) ellipses have an extra key type with value `elliptical` besides the array part containing the knot list.

12.3.2 Colors

A color is an integer array with 0, 1, 3 or 4 values:

FIELD	TYPE	EXPLANATION
0	marking only	no values
1	greyscale	one value in the range (0, 1), 'black' is 0
3	rgb	three values in the range (0, 1), 'black' is 0, 0, 0
4	cmymk	four values in the range (0, 1), 'black' is 0, 0, 0, 1

If the color model of the internal object was uninitialized, then it was initialized to the values representing 'black' in the colorspace `defaultcolormodel` that was in effect at the time of the shipout.

12.3.3 Transforms

Each transform is a six-item array.

INDEX	TYPE	EXPLANATION
1	number	represents x
2	number	represents y
3	number	represents xx
4	number	represents yx
5	number	represents xy
6	number	represents yy

Note that the translation (index 1 and 2) comes first. This differs from the ordering in PostScript, where the translation comes last.

12.3.4 Dashes

Each dash is a hash with two items. We use the same model as PostScript for the representation of the dashlist. `dashes` is an array of 'on' and 'off', values, and `offset` is the phase of the pattern.

FIELD	TYPE	EXPLANATION
<code>dashes</code>	hash	an array of on-off numbers
<code>offset</code>	number	the starting offset value



12.3.5 Pens and peninfo

There is helper function (`peninfo(obj)`) that returns a table containing a bunch of vital characteristics of the used pen (all values are floats):

FIELD	TYPE	EXPLANATION
width	number	width of the pen
sx	number	x scale
rx	number	x y multiplier
ry	number	y x multiplier
sy	number	y scale
tx	number	x offset
ty	number	y offset

12.3.6 Character size information

These functions find the size of a glyph in a defined font. The fontname is the same name as the argument to `infont`; the char is a glyph id in the range 0 to 255; the returned w is in AFM units.

```
<number> w = char_width(mp,<string> fontname, <number> char)
<number> h = char_height(mp,<string> fontname, <number> char)
<number> d = char_depth(mp,<string> fontname, <number> char)
```

12.4 Scanners

After a relative long period of testing the scanners are now part of the interface. That doesn't mean that there will be no changes: depending on the needs and experiences details might evolve. The summary below is there still preliminary and mostly provided as reminder.

SCANNER	ARGUMENT	RETURNS
scannext	instance, keep	token, mode, type
scanexpression	instance, keep	type
scantoken	instance, keep	token, mode, kind
scansymbol	instance, keep, expand	string
scannumeric	instance, type	number
scaninteger	instance, type	integer
scanboolean	instance, type	boolean
scanstring	instance, type	string
scanpair	instance, hashed, type	table or two numbers
scancolor	instance, hashed, type	table or three numbers
scancmykcolor	instance, hashed, type	table or four numbers
scantransform	instance, hashed, type	table or six numbers
scanpath	instance, hashed, type	table with hashes or arrays
scanpen	instance, hashed, type	table with hashes or arrays



The types and token codes are numbers but they actually depend on the implementation (although changes are unlikely). The types of data structures can be queried with `mplib.gettypes()`:

0: undefined, 1: vacuous, 2: boolean, 3: unknownboolean, 4: string, 5: unknownstring, 6: pen, 7: unknownpen, 8: path, 9: unknownpath, 10: picture, 11: unknownpicture, 12: transform, 13: color, 14: cmykcolor, 15: pair, 16: numeric, 17: known, 18: dependent, 19: protodependent, 20: independent, 21: tokenlist, 22: structured, 23: unsuffixedmacro, 24: suffixedmacro.

The command codes are available with `mplib.getcodes()`:

0: undefined, 1: btex, 2: etex, 3: if, 4: fi_or_else, 5: input, 6: iteration, 7: repeat_loop, 8: exitif, 9: relax, 10: scantokens, 11: runscript, 12: maketext, 13: expandafter, 14: definedmacro, 15: save, 16: interim, 17: let, 18: newinternal, 19: def, 20: shipout, 21: addto, 22: setbounds, 23: scope, 24: protection, 25: show, 26: mode, 27: randomseed, 28: message, 29: everyjob, 30: delimiters, 31: write, 32: declare, 33: leftdelimiter, 34: begingroup, 35: nullary, 36: unary, 37: str, 38: void, 39: cycle, 40: ofbinary, 41: capsule, 42: string, 43: internal, 44: tag, 45: numeric, 46: plus_or_minus, 47: secondarydef, 48: tertiarybinary, 49: leftbrace, 50: join, 51: ampersand, 52: tertiarydef, 53: primarybinary, 54: equals, 55: and, 56: primarydef, 57: slash, 58: secondarybinary, 59: parametertype, 60: controls, 61: tension, 62: atleast, 63: curl, 64: macrospecial, 65: rightdelimiter, 66: leftbracket, 67: rightbracket, 68: rightbrace, 69: with, 70: thingstoadd, 71: of, 72: to, 73: step, 74: until, 75: within, 76: assignment, 77: skip, 78: colon, 79: comma, 80: semicolon, 81: endgroup, 82: stop, 83: outertag, 84: undefinedcs.

Now, if you really want to use these, keep in mind that the internals of MetaPost are not trivial, especially because expression scanning can be complex. So you need to experiment a bit. In ConTeXt all is (and will be) hidden below an abstraction layer so users are not bothered by all these look-ahead and push-back issues that originate in the way MetaPost scans its input.

12.5 Injectors

It is important to know that piping code into the library is pretty fast and efficient. Most processing time relates to memory management, calculations and generation of output can not be neglected either. Out of curiosity I added some functions that directly push data into the library but the gain is not that large.⁶

SCANNER	ARGUMENT
<code>injectnumeric</code>	instance, number
<code>injectinteger</code>	instance, number
<code>injectboolean</code>	instance, boolean
<code>injectstring</code>	instance, string
<code>injectpair</code>	instance, (table with) two numbers
<code>injectcolor</code>	instance, (table with) three numbers
<code>injectcmykcolor</code>	instance, (table with) four numbers

⁶ The main motivation was checking of huge paths could be optimized. The other data structures were then added for completeness.



`injecttransform` instance, (table with) six numbers
`injectpath` instance, table with hashes or arrays, cycle, variant

The path injector takes a table with subtables that are either hashed (like the path solver) or arrays with two, four or six entries. When the third argument has the value `true` the path is closed. When the fourth argument is `true` the path is constructed out of straight lines (as with `--`) by setting the `curl` values to 1 automatically.⁷

⁷ This is all experimental so future versions might provide more control.





13 The pdf related libraries

13.1 The pdfe library

13.1.1 Introduction

The pdfe library replaces the epdf library and provides an interface to pdf files. It uses the same code as is used for pdf image inclusion. The pplib library by Paweł Jackowski replaces the poppler (derived from xpdf) library.

A pdf file is basically a tree of objects and one descends into the tree via dictionaries (key/value) and arrays (index/value). There are a few topmost dictionaries that start at root that are accessed more directly.

Although everything in pdf is basically an object we only wrap a few in so called userdata Lua objects.

TYPE	MAPPING
pdf	Lua
null	nil
boolean	boolean
integer	integer
float	number
name	string
string	string
array	array userdata
dictionary	dictionary userdata
stream	stream userdata (with related dictionary)
reference	reference userdata

The regular getters return these Lua data types but one can also get more detailed information.

13.1.2 open, openfile, new, getstatus, close, unencrypt

A document is loaded from a file (by name or handle) or string:

```
<pdf document> = pdfe.open(filename)
<pdf document> = pdfe.openfile(filehandle)
<pdf document> = pdfe.new(somestring,somelength)
```

Such a document is closed with:

```
pdfe.close(<pdf document>)
```

You can check if a document opened well by:



```
pdfe.getstatus(<pdf document>)
```

The returned codes are:

VALUE	EXPLANATION
-2	the document failed to open
-1	the document is (still) protected
0	the document is not encrypted
2	the document has been unencrypted

An encrypted document can be unencrypted by the next command where instead of either password you can give nil:

```
pdfe.unencrypt(<pdf document>, userpassword, ownerpassword)
```

13.1.3 getsize, getversion, getnofobjects, getnofpages

A successfully opened document can provide some information:

```
bytes = getsize(<pdf document>)  
major, minor = getversion(<pdf document>)  
n = getnofobjects(<pdf document>)  
n = getnofpages(<pdf document>)  
bytes, waste = getnofpages(<pdf document>)
```

13.1.4 get[catalog|trailer|info]

For accessing the document structure you start with the so called catalog, a dictionary:

```
<pdf dictionary> = pdfe.getcatalog(<pdf document>)
```

The other two root dictionaries are accessed with:

```
<pdf dictionary> = pdfe.gettrailer(<pdf document>)  
<pdf dictionary> = pdfe.getinfo(<pdf document>)
```

13.1.5 getpage, getbox

A specific page can conveniently be reached with the next command, which returns a dictionary.

```
<pdf dictionary> = pdfe.getpage(<pdf document>, pagenumber)
```

Another convenience command gives you the (bounding) box of a (normally page) which can be inherited from the document itself. An example of a valid box name is MediaBox.

```
pages = pdfe.getbox(<pdf dictionary>, boxname)
```



13.1.6 get[string|integer|number|boolean|name]

Common values in dictionaries and arrays are strings, integers, floats, booleans and names (which are also strings) and these are also normal Lua objects:

```
s = getstring (<pdf array|dictionary>,index|key)
i = getinteger(<pdf array|dictionary>,index|key)
n = getnumber (<pdf array|dictionary>,index|key)
b = getboolean(<pdf array|dictionary>,index|key)
n = getname   (<pdf array|dictionary>,index|key)
```

The getstring function has two extra variants:

```
s, h = getstring (<pdf array|dictionary>,index|key,false)
s     = getstring (<pdf array|dictionary>,index|key,true)
```

The first call returns the original string plus a boolean indicating if the string is hex encoded. The second call returns the unencoded string.

13.1.7 get[dictionary|array|stream]

Normally you will use an index in an array and key in a dictionary but dictionaries also accept an index. The size of an array or dictionary is available with the usual # operator.

```
<pdf dictionary> = getdictionary(<pdf array|dictionary>,index|key)
<pdf array>      = getarray      (<pdf array|dictionary>,index|key)
<pdf stream>,
<pdf dictionary> = getstream    (<pdf array|dictionary>,index|key)
```

These commands return dictionaries, arrays and streams, which are dictionaries with a blob of data attached.

Before we come to an alternative access mode, we mention that the objects provide access in a different way too, for instance this is valid:

```
print(pdf.open("foo.pdf").Catalog.Type)
```

At the topmost level there are Catalog, Info, Trailer and Pages, so this is also okay:

```
print(pdf.open("foo.pdf").Pages[1])
```

13.1.8 [open|close|readfrom|whole|]stream

Streams are sort of special. When your index or key hits a stream you get back a stream object and dictionary object. The dictionary you can access in the usual way and for the stream there are the following methods:

```
okay = openstream(<pdf stream>,[decode])
      closestream(<pdf stream>)
```



```
str, n = readfromstream(<pdf stream>)
str, n = readwholestream(<pdf stream>,[decode])
```

You either read in chunks, or you ask for the whole. When reading in chunks, you need to open and close the stream yourself. The n value indicates the length read. The decode parameter controls if the stream data gets uncompressed.

As with dictionaries, you can access fields in a stream dictionary in the usual Lua way too. You get the content when you 'call' the stream. You can pass a boolean that indicates if the stream has to be decompressed.

13.1.9 getfrom[dictionary|array]

In addition to the interface described before, there is also a bit lower level interface available.

```
key, type, value, detail = getfromdictionary(<pdf dictionary>,index)
type, value, detail = getfromarray(<pdf array>,index)
```

TYPE	MEANING	VALUE	DETAIL
0	none	nil	
1	null	nil	
2	boolean	boolean	
3	integer	integer	
4	number	float	
5	name	string	
6	string	string	hex
7	array	arrayobject	size
8	dictionary	dictionaryobject	size
9	stream	streamobject	dictionary size
10	reference	integer	

A hex string is (in the pdf file) surrounded by <> while plain strings are bounded by <>.

13.1.10 [dictionary|array]totable

All entries in a dictionary or table can be fetched with the following commands where the return values are a hashed or indexed table.

```
hash = dictionarytotable(<pdf dictionary>)
list = arraytotable(<pdf array>)
```

You can get a list of pages with:

```
{ { <pdf dictionary>, size, objnum }, ... } = pagestotable(<pdf document>)
```



13.1.11 getfromreference

Because you can have unresolved references, a reference object can be resolved with:

```
type, <pdf dictionary|array|stream>, detail = getfromreference(<pdf reference>)
```

So, as second value you get back a new pdf userdata object that you can query.

13.2 Memory streams

The `pdf.new` function takes three arguments:

VALUE	EXPLANATION
stream	this is a (in low level Lua speak) light userdata object, i.e. a pointer to a sequence of bytes
length	this is the length of the stream in bytes (the stream can have embedded zeros)
name	optional, this is a unique identifier that is used for hashing the stream

The third argument is optional. When it is not given the function will return a pdf document object as with a regular file, otherwise it will return a filename that can be used elsewhere (e.g. in the image library) to reference the stream as pseudo file.

Instead of a light userdata stream (which is actually fragile but handy when you come from a library) you can also pass a Lua string, in which case the given length is (at most) the string length.

The function returns a pdf object and a string. The string can be used in the `img` library instead of a filename. You need to prevent garbage collection of the object when you use it as image (for instance by storing it somewhere).

Both the memory stream and it's use in the image library is experimental and can change. In case you wonder where this can be used: when you use the `swiglib` library for `graphicmagick`, it can return such a userdata object. This permits conversion in memory and passing the result directly to the backend. This might save some runtime in one-pass workflows. This feature is currently not meant for production and we might come up with a better implementation.

13.3 The pdfscanner library

This library is not available in LuaMetaTeX.





14 Extra libraries

14.1 Introduction

The libraries can be grouped in categories like fonts, languages, T_EX, MetaPost, pdf, etc. There are however also some that are more general purpose and these are discussed here.

14.2 File and string readers: `fio` and `sio`

This library provides a set of functions for reading numbers from a file and in addition to the regular `io` library functions. The following work on normal Lua file handles.

NAME	ARGUMENTS	RESULTS
<code>readcardinal1</code>	(f)	a 1 byte unsigned integer
<code>readcardinal2</code>	(f)	a 2 byte unsigned integer
<code>readcardinal3</code>	(f)	a 3 byte unsigned integer
<code>readcardinal4</code>	(f)	a 4 byte unsigned integer
<code>readcardinaltable</code>	(f,n,b)	n cardinals of b bytes
<code>readinteger1</code>	(f)	a 1 byte signed integer
<code>readinteger2</code>	(f)	a 2 byte signed integer
<code>readinteger3</code>	(f)	a 3 byte signed integer
<code>readinteger4</code>	(f)	a 4 byte signed integer
<code>readintegertable</code>	(f,n,b)	n integers of b bytes
<code>readfixed2</code>	(f)	a float made from a 2 byte fixed format
<code>readfixed4</code>	(f)	a float made from a 4 byte fixed format
<code>read2dot14</code>	(f)	a float made from a 2 byte in 2dot4 format
<code>setposition</code>	(f,p)	goto position p
<code>getposition</code>	(f)	get the current position
<code>skipposition</code>	(f,n)	skip n positions
<code>readbytes</code>	(f,n)	n bytes
<code>readbytetable</code>	(f,n)	n bytes

When relevant there are also variants that end with `le` that do it the little endian way. The fixed and dot floating points formats are found in font files and return Lua doubles.

A similar set of function as in the `fio` library is available in the `sio` library: `sio.readcardinal1`, `sio.readcardinal2`, `sio.readcardinal3`, `sio.readcardinal4`, `sio.readcardinaltable`, `sio.readinteger1`, `sio.readinteger2`, `sio.readinteger3`, `sio.readinteger4`, `sio.readintegertable`, `sio.readfixed2`, `sio.readfixed4`, `sio.read2dot14`, `sio.setposition`, `sio.getposition`, `sio.skipposition`, `sio.readbytes` and `sio.readbytetable`. Here the first argument is a string instead of a file handle.



14.3 md5

NAME	ARGUMENTS	RESULTS
sum		
hex		
HEX		

14.4 sha2

NAME	ARGUMENTS	RESULTS
digest256		
digest384		
digest512		

14.5 xzip

NAME	ARGUMENTS	RESULTS
compress		
decompress		
adler32		
crc32		

14.6 xmath

This library just opens up standard C math library and the main reason for it being there is that it permits advanced graphics in MetaPost (via the Lua interface). There are three constant values:

NAME	ARGUMENTS	RESULTS
inf	–	inf
nan	–	nan
pi	–	3.1415926535898

and a lot of functions:

NAME	ARGUMENTS	RESULTS
acos	(a)	
acosh	(a)	
asin	(a)	
asinh	(a)	
atan	(a[,b])	
atan2	(a[,b])	
atanh	(a)	
cbrt	(a)	



ceil	(a)
copysign	(a,b)
cos	(a)
cosh	(a)
deg	(a)
erf	(a)
erfc	(a)
exp	(a)
exp2	(a)
expm1	(a)
fabs	(a)
fdim	(a,b)
floor	(a)
fma	(a,b,c)
fmax	(...)
fmin	(...)
fmod	(a,b)
frexp	(a,b)
gamma	(a)
hypot	(a,b)
isfinite	(a)
isinf	(a)
isnan	(a)
isnormal	(a)
j0	(a)
j1	(a)
jn	(a,b)
ldexp	(a,b)
lgamma	(a)
l0	(a)
l1	(a)
ln	(a,b)
log	(a[,b])
log10	(a)
log1p	(a)
log2	(a)
logb	(a)
modf	(a,b)
nearbyint	(a)
nextafter	(a,b)
pow	(a,b)
rad	(a)
remainder	(a,b)
remquo	(a,b)
round	(a)
scalbn	(a,b)



sin	(a)
sinh	(a)
sqrt	(a)
tan	(a)
tanh	(a)
tgamma	(a)
trunc	(a)
y0	(a)
y1	(a)
yn	(a)

14.7 xcomplex

LuaMetaTeX also provides a complex library `xcomplex`. The complex number is a userdata:

NAME	ARGUMENTS	RESULTS
<code>new</code>	(r,i)	a complex userdata type
<code>tostring</code>	(z)	a string representation
<code>topair</code>	(z)	two numbers

There is a bunch of functions that take a complex number:

NAME	ARGUMENTS	RESULTS
<code>abs</code>	(a)	
<code>arg</code>	(a)	
<code>imag</code>	(a)	
<code>real</code>	(a)	
<code>onj</code>	(a)	
<code>proj</code>	(a)	
<code>exp"</code>	(a)	
<code>log</code>	(a)	
<code>sqrt</code>	(a)	
<code>pow</code>	(a,b)	
<code>sin</code>	(a)	
<code>cos</code>	(a)	
<code>tan</code>	(a)	
<code>asin</code>	(a)	
<code>acos</code>	(a)	
<code>atan</code>	(a)	
<code>sinh</code>	(a)	
<code>cosh</code>	(a)	
<code>tanh</code>	(a)	
<code>asinh</code>	(a)	
<code>acosh</code>	(a)	
<code>atanh</code>	(a)	



These are accompanied by `libcerf` functions:

NAME	ARGUMENTS	RESULTS
<code>erf</code>	(a)	The complex error function $\operatorname{erf}(z)$
<code>erfc</code>	(a)	The complex complementary error function $\operatorname{erfc}(z) = 1 - \operatorname{erf}(z)$
<code>erfcx</code>	(a)	The underflow-compensating function $\operatorname{erfcx}(z) = \exp(z^2) \operatorname{erfc}(z)$
<code>erfi</code>	(a)	The imaginary error function $\operatorname{erfi}(z) = -i \operatorname{erf}(iz)$
<code>dawson</code>	(a)	Dawson's integral $D(z) = \sqrt{\pi}/2 * \exp(-z^2) * \operatorname{erfi}(z)$
<code>voigt</code>	(a,b,c)	The convolution of a Gaussian and a Lorentzian
<code>voigt_hwhm</code>	(a,b)	The half width at half maximum of the Voigt profile

14.8 xdecimal

As an experiment `LuaMetaTeX` provides an interface to the `decNumber` library that we have on board for `MetaPost` anyway. Apart from the usual support for operators there are some functions.

NAME	ARGUMENTS	RESULTS
<code>abs</code>	(a)	
<code>new</code>	([n or s])	
<code>copy</code>	(a)	
<code>trim</code>	(a)	
<code>tostring</code>	(a)	
<code>tonumber</code>	(a)	
<code>setprecision</code>	(n)	
<code>getprecision</code>	()	
<code>conj</code>	(a)	
<code>abs</code>	(a)	
<code>pow</code>	(a,b)	
<code>sqrt</code>	(a)	
<code>ln</code>	(a)	
<code>log</code>	(a)	
<code>exp</code>	(a)	
<code>bor</code>	(a,b)	
<code>bxor</code>	(a,b)	
<code>band</code>	(a,b)	
<code>shift</code>	(a,b)	
<code>rotate</code>	(a,b)	
<code>minus</code>	(a)	
<code>plus</code>	(a)	
<code>min</code>	(a,b)	
<code>max</code>	(a,b)	

14.9 lfs

The original `lfs` module has been adapted a bit to our needs but for practical reasons we kept



the namespace. This module will probably evolve a bit over time.

NAME	ARGUMENTS	RESULTS
attributes	(name)	
chdir	(name)	
currentdir	()	
dir	(name)	name, mode, size and mtime
mkdir	(name)	
rmdir	(name)	
touch	(name)	
link	(name)	
symlinkattributes	(name)	
isdir	(name)	
isfile	(name)	
iswriteabledir	(name)	
iswriteablefile	(name)	
isreadabledir	(name)	
isreadablefile	(name)	

The `dir` function is a traverser which in addition to the name returns some more properties. Keep in mind that the traverser loops over a directory and that it doesn't run well when used nested. This is a side effect of the operating system. It is also the reason why we return some properties because querying them via `attributes` would interfere badly.

The following attributes are returned by `attributes`:

NAME	VALUE
mode	
size	
modification	
access	
change	
permissions	
nlink	

14.10 pngdecode

This module is experimental and used in image inclusion. It is not some general purpose module and is supposed to be used in a very controlled way. The interfaces might evolve.

NAME	ARGUMENTS	RESULTS
applyfilter	(str,nx,ny,slice)	string
splitmask	(str,nx,ny,bpp,bytes)	string
interlace	(str,nx,ny,slice,pass)	string
expand	(str,nx,ny,parts,xline,factor)	string



14.11 basexx

Some more experimental helpers:

NAME	ARGUMENTS	RESULTS
encode16	(str[,newline])	string
decode16	(str)	string
encode64	(str[,newline])	string
decode64	(str)	string
encode85	(str[,newline])	string
decode85	(str)	string
encodeRL	(str)	string
decodeRL	(str)	string
encodeLZW	(str[,defaults])	string
decodeLZW	(str[,defaults])	string

14.12 Multibyte string functions

The `string` library has a few extra functions, for example `string.explode`. This function takes upto two arguments: `string.explode(s[,m])` and returns an array containing the string argument `s` split into sub-strings based on the value of the string argument `m`. The second argument is a string that is either empty (this splits the string into characters), a single character (this splits on each occurrence of that character, possibly introducing empty strings), or a single character followed by the plus sign `+` (this special version does not create empty sub-strings). The default value for `m` is `' '` (multiple spaces). Note: `m` is not hidden by surrounding braces as it would be if this function was written in $\text{T}_{\text{E}}\text{X}$ macros.

The `string` library also has six extra iterators that return strings piecemeal: `string.utfvalues`, `string.utfcharacters`, `string.characters`, `string.characterpairs`, `string.bytes` and `string.bytepairs`.

- ▶ `string.utfvalues(s)`: an integer value in the Unicode range
- ▶ `string.utfcharacters(s)`: a string with a single utf-8 token in it
- ▶ `string.characters(s)`: a string containing one byte
- ▶ `string.characterpairs(s)`: two strings each containing one byte or an empty second string if the string length was odd
- ▶ `string.bytes(s)`: a single byte value
- ▶ `string.bytepairs(s)`: two byte values or nil instead of a number as its second return value if the string length was odd

The `string.characterpairs()` and `string.bytepairs()` iterators are useful especially in the conversion of utf16 encoded data into utf8.

There is also a two-argument form of `string.dump()`. The second argument is a boolean which, if true, strips the symbols from the dumped data. This matches an extension made in `luajit`. This is typically a function that gets adapted as Lua itself progresses.

The `string` library functions `len`, `lower`, `sub` etc. are not Unicode-aware. For strings in the



utf8 encoding, i.e., strings containing characters above code point 127, the corresponding functions from the `slnunicode` library can be used, e.g., `unicode.utf8.len`, `unicode.utf8.lower` etc. The exceptions are `unicode.utf8.find`, that always returns byte positions in a string, and `unicode.utf8.match` and `unicode.utf8.gmatch`. While the latter two functions in general *are* Unicode-aware, they fall-back to non-Unicode-aware behavior when using the empty capture `()` but other captures work as expected. For the interpretation of character classes in `unicode.utf8` functions refer to the library sources at <http://luaforge.net/projects/sln>.

Version 5.3 of Lua provides some native utf8 support but we have added a few similar helpers too: `string.utfvalue`, `string.utfcharacter` and `string.utflength`.

- ▶ `string.utfvalue(s)`: returns the codepoints of the characters in the given string
- ▶ `string.utfcharacter(c, ...)`: returns a string with the characters of the given code points
- ▶ `string.utflength(s)`: returns the length of the given string

These three functions are relative fast and don't do much checking. They can be used as building blocks for other helpers.

14.13 Extra os library functions

The `os` library has a few extra functions and variables: `os.selfdir`, `os.selfarg`, `os.setenv`, `os.env`, `os.gettimeofday`, `os.type`, `os.name` and `os.uname`, that we will discuss here. There are also some time related helpers in the `lua` namespace.

- ▶ `os.selfdir` is a variable that holds the directory path of the actual executable. For example: `\directlua{tex.sprint(os.selfdir)}`.
- ▶ `os.selfarg` is a table with the command line arguments.
- ▶ `os.setenv(key,value)` sets a variable in the environment. Passing `nil` instead of a value string will remove the variable.
- ▶ `os.env` is a hash table containing a dump of the variables and values in the process environment at the start of the run. It is writeable, but the actual environment is *not* updated automatically.
- ▶ `os.gettimeofday` returns the current 'Unix time', but as a float. Keep in mind that there might be platforms where this function is not available.
- ▶ `os.type` is a string that gives a global indication of the class of operating system. The possible values are currently `windows`, `unix`, and `msdos` (you are unlikely to find this value 'in the wild').
- ▶ `os.name` is a string that gives a more precise indication of the operating system. These possible values are not yet fixed, and for `os.type` values `windows` and `msdos`, the `os.name` values are simply `windows` and `msdos`

The list for the type `unix` is more precise: `linux`, `freebsd`, `kfreebsd`, `cygwin`, `openbsd`, `solaris`, `sunos` (pre-solaris), `hpux`, `irix`, `macosx`, `gnu` (hurd), `bsd` (unknown, but bsd-like), `sysv`, `generic` (unknown). But ... we only provide LuaMetaTeX binaries for the mainstream variants.

Officially we only support mainstream systems: MS Windows, linux, FreeBSD and os-x. Of course one can build LuaMetaTeX for other systems, in which case one has to check the above.

- ▶ `os.uname` returns a table with specific operating system information acquired at runtime. The keys in the returned table are all string values, and their names are: `sysname`, `machine`,



release, version, and nodename.

14.14 The lua library functions

The lua library provides some general helpers.

- ▶ The `newtable` and `newindex` functions can be used to create tables with space reserved beforehand for the given amount of entries.
- ▶ The `getstacktop` function returns a number that can be used for diagnostic purposes.
- ▶ The functions `getruntime`, `getcurrenttime`, `getpreciseticks` and `getpreciseseconds` return what their name suggests.
- ▶ On MS Windows the `getcodepage` function returns two numbers, one for the command handler and one for the graphical user interface.
- ▶ The name of the startup file is reported by `getstartupfile`.
- ▶ The Lua version is reported by `getversion`.
- ▶ The `lua.openfile` function can be used instead of `io.open`. On MS Windows it will convert the filename to a so called wide one which means that filenames in utf8 encoding will work ok. On the other hand, names given in the codepage won't.





Primitive codes

here follows a list with all primitives and their category is shown. When the engine starts up in ini mode all primitives get defined along with some properties that makes it possible to do a reverse lookup of a combination of command code and char code. But, a primitive, being also a regular command can be redefined later on. The table below shows the original pairs but in ConT_EXt some of these primitives are redefined. However, any macro that fits a command and char pair is (reported as) a primitive in logs and error messages. In the end all tokens are such a combination, The first 16 command codes are reserved for characters (the whole Unicode range can be used as char code) with specific catcodes and not mentioned in the list.

PRIMITIVE	COMMAND CODE	CHAR CODE	ORIGIN
\	explicit_space	0	tex
\-	discretionary	1	tex
\/	italic_correction	0	tex
\UUskewed	math_fraction	7	luatex
\UUskewedwithdelims	math_fraction	15	luatex
\Uabove	math_fraction	4	luatex
\Uabovewithdelims	math_fraction	12	luatex
\Uatop	math_fraction	6	luatex
\Uatopwithdelims	math_fraction	14	luatex
\Uchar	convert	14	luatex
\Udelcode	define_char_code	9	luatex
\Udelcodenum	define_char_code	10	luatex
\Udelimiter	delimiter_number	1	luatex
\Udelimiterover	math_radical	6	luatex
\Udelimiterunder	math_radical	5	luatex
\Uhextensible	math_radical	7	luatex
\Uleft	math_fence	5	luatex
\Umathaccent	math_accent	1	luatex
\Umathaccentbaseheight	set_math_parameter	2	luatex
\Umathaccentvariant	set_math_parameter	127	luatex
\Umathadapttoleft	math_modifier	4	luatex
\Umathadaptright	math_modifier	5	luatex
\Umathaxis	set_math_parameter	1	luatex
\Umathbinbinspacing	set_math_parameter	70	luatex
\Umathbinclonespacing	set_math_parameter	73	luatex
\Umathbininnerspacing	set_math_parameter	75	luatex
\Umathbinopenspacing	set_math_parameter	72	luatex
\Umathbinopspacing	set_math_parameter	69	luatex
\Umathbinordspacing	set_math_parameter	68	luatex
\Umathbinpunctspacing	set_math_parameter	74	luatex
\Umathbinrelspacing	set_math_parameter	71	luatex
\Umathbotaccentvariant	set_math_parameter	129	luatex
\Umathchar	math_char_number	1	luatex



<code>\Umathcharclass</code>	<code>some_item</code>	25	luatex
<code>\Umathchardef</code>	<code>shorthand_def</code>	2	luatex
<code>\Umathcharfam</code>	<code>some_item</code>	26	luatex
<code>\Umathcharnum</code>	<code>math_char_number</code>	2	luatex
<code>\Umathcharnumdef</code>	<code>shorthand_def</code>	3	luatex
<code>\Umathcharslot</code>	<code>some_item</code>	27	luatex
<code>\Umathclass</code>	<code>math_char_number</code>	3	luatex
<code>\Umathclosebinspacing</code>	<code>set_math_parameter</code>	94	luatex
<code>\Umathcloseclosespacing</code>	<code>set_math_parameter</code>	97	luatex
<code>\Umathcloseinnerspacing</code>	<code>set_math_parameter</code>	99	luatex
<code>\Umathcloseopenspacing</code>	<code>set_math_parameter</code>	96	luatex
<code>\Umathcloseopspacing</code>	<code>set_math_parameter</code>	93	luatex
<code>\Umathcloseordspacing</code>	<code>set_math_parameter</code>	92	luatex
<code>\Umathclosepunctspacing</code>	<code>set_math_parameter</code>	98	luatex
<code>\Umathcloserelspacing</code>	<code>set_math_parameter</code>	95	luatex
<code>\Umathcode</code>	<code>define_char_code</code>	6	luatex
<code>\Umathcodenum</code>	<code>define_char_code</code>	7	luatex
<code>\Umathconnectoroverlapmin</code>	<code>set_math_parameter</code>	51	luatex
<code>\Umathdegreevariant</code>	<code>set_math_parameter</code>	126	luatex
<code>\Umathdelimiterovervariant</code>	<code>set_math_parameter</code>	120	luatex
<code>\Umathdelimiterundervariant</code>	<code>set_math_parameter</code>	121	luatex
<code>\Umathdenominatorvariant</code>	<code>set_math_parameter</code>	132	luatex
<code>\Umathfractiondelsize</code>	<code>set_math_parameter</code>	25	luatex
<code>\Umathfractiondenomdown</code>	<code>set_math_parameter</code>	24	luatex
<code>\Umathfractiondenomvgap</code>	<code>set_math_parameter</code>	23	luatex
<code>\Umathfractionnumup</code>	<code>set_math_parameter</code>	22	luatex
<code>\Umathfractionnumvgap</code>	<code>set_math_parameter</code>	21	luatex
<code>\Umathfractionrule</code>	<code>set_math_parameter</code>	20	luatex
<code>\Umathfractionvariant</code>	<code>set_math_parameter</code>	124	luatex
<code>\Umathhextensiblevariant</code>	<code>set_math_parameter</code>	122	luatex
<code>\Umathinnerbinspacing</code>	<code>set_math_parameter</code>	110	luatex
<code>\Umathinnerclosespacing</code>	<code>set_math_parameter</code>	113	luatex
<code>\Umathinnerinnerspacing</code>	<code>set_math_parameter</code>	115	luatex
<code>\Umathinneropenspacing</code>	<code>set_math_parameter</code>	112	luatex
<code>\Umathinneropspacing</code>	<code>set_math_parameter</code>	109	luatex
<code>\Umathinnerordspacing</code>	<code>set_math_parameter</code>	108	luatex
<code>\Umathinnerpunctspacing</code>	<code>set_math_parameter</code>	114	luatex
<code>\Umathinnerrelspacing</code>	<code>set_math_parameter</code>	111	luatex
<code>\Umathlimitabovebgap</code>	<code>set_math_parameter</code>	29	luatex
<code>\Umathlimitabovekern</code>	<code>set_math_parameter</code>	30	luatex
<code>\Umathlimitabovevgap</code>	<code>set_math_parameter</code>	28	luatex
<code>\Umathlimitbelowbgap</code>	<code>set_math_parameter</code>	32	luatex
<code>\Umathlimitbelowkern</code>	<code>set_math_parameter</code>	33	luatex
<code>\Umathlimitbelowvgap</code>	<code>set_math_parameter</code>	31	luatex
<code>\Umathlimits</code>	<code>math_modifier</code>	1	luatex
<code>\Umathnoaxis</code>	<code>math_modifier</code>	7	luatex



<code>\Umathnolimits</code>	<code>math_modifier</code>	2	luatex
<code>\Umathnolimitsubfactor</code>	<code>set_math_parameter</code>	34	luatex
<code>\Umathnolimitsupfactor</code>	<code>set_math_parameter</code>	35	luatex
<code>\Umathnumeratorvariant</code>	<code>set_math_parameter</code>	131	luatex
<code>\Umathopbinspacing</code>	<code>set_math_parameter</code>	62	luatex
<code>\Umathopclonespacing</code>	<code>set_math_parameter</code>	65	luatex
<code>\Umathopenbinspacing</code>	<code>set_math_parameter</code>	86	luatex
<code>\Umathopenclosespacing</code>	<code>set_math_parameter</code>	89	luatex
<code>\Umathopeninnerspacing</code>	<code>set_math_parameter</code>	91	luatex
<code>\Umathopenopenspacing</code>	<code>set_math_parameter</code>	88	luatex
<code>\Umathopenopspacing</code>	<code>set_math_parameter</code>	85	luatex
<code>\Umathopenordspacing</code>	<code>set_math_parameter</code>	84	luatex
<code>\Umathopenpunctspacing</code>	<code>set_math_parameter</code>	90	luatex
<code>\Umathopenrelspacing</code>	<code>set_math_parameter</code>	87	luatex
<code>\Umathopenupdepth</code>	<code>math_modifier</code>	11	luatex
<code>\Umathopenupheight</code>	<code>math_modifier</code>	10	luatex
<code>\Umathoperatorsize</code>	<code>set_math_parameter</code>	4	luatex
<code>\Umathopinnerspacing</code>	<code>set_math_parameter</code>	67	luatex
<code>\Umathopopenspacing</code>	<code>set_math_parameter</code>	64	luatex
<code>\Umathopopspacing</code>	<code>set_math_parameter</code>	61	luatex
<code>\Umathopordspacing</code>	<code>set_math_parameter</code>	60	luatex
<code>\Umathoppunctspacing</code>	<code>set_math_parameter</code>	66	luatex
<code>\Umathoprelspacing</code>	<code>set_math_parameter</code>	63	luatex
<code>\Umathordbinspacing</code>	<code>set_math_parameter</code>	54	luatex
<code>\Umathordclonespacing</code>	<code>set_math_parameter</code>	57	luatex
<code>\Umathordinnerspacing</code>	<code>set_math_parameter</code>	59	luatex
<code>\Umathordopenspacing</code>	<code>set_math_parameter</code>	56	luatex
<code>\Umathordopspacing</code>	<code>set_math_parameter</code>	53	luatex
<code>\Umathordordspacing</code>	<code>set_math_parameter</code>	52	luatex
<code>\Umathordpunctspacing</code>	<code>set_math_parameter</code>	58	luatex
<code>\Umathordrelspacing</code>	<code>set_math_parameter</code>	55	luatex
<code>\Umathoverbarkern</code>	<code>set_math_parameter</code>	5	luatex
<code>\Umathoverbarrule</code>	<code>set_math_parameter</code>	6	luatex
<code>\Umathoverbarvgap</code>	<code>set_math_parameter</code>	7	luatex
<code>\Umathoverdelimiterbgap</code>	<code>set_math_parameter</code>	39	luatex
<code>\Umathoverdelimitervariant</code>	<code>set_math_parameter</code>	118	luatex
<code>\Umathoverdelimitervgap</code>	<code>set_math_parameter</code>	38	luatex
<code>\Umathoverlayaccentvariant</code>	<code>set_math_parameter</code>	130	luatex
<code>\Umathoverlinevariant</code>	<code>set_math_parameter</code>	116	luatex
<code>\Umathphantom</code>	<code>math_modifier</code>	8	luatex
<code>\Umathpunctbinspacing</code>	<code>set_math_parameter</code>	102	luatex
<code>\Umathpunctclonespacing</code>	<code>set_math_parameter</code>	105	luatex
<code>\Umathpunctinnerspacing</code>	<code>set_math_parameter</code>	107	luatex
<code>\Umathpunctopenspacing</code>	<code>set_math_parameter</code>	104	luatex
<code>\Umathpunctopspacing</code>	<code>set_math_parameter</code>	101	luatex
<code>\Umathpunctordspacing</code>	<code>set_math_parameter</code>	100	luatex



<code>\Umathpunctpunctspacing</code>	<code>set_math_parameter</code>	106	luatex
<code>\Umathpunctrelspacing</code>	<code>set_math_parameter</code>	103	luatex
<code>\Umathquad</code>	<code>set_math_parameter</code>	0	luatex
<code>\Umathradicaldegreeafter</code>	<code>set_math_parameter</code>	15	luatex
<code>\Umathradicaldegreebefore</code>	<code>set_math_parameter</code>	14	luatex
<code>\Umathradicaldegreeraise</code>	<code>set_math_parameter</code>	16	luatex
<code>\Umathradicalkern</code>	<code>set_math_parameter</code>	11	luatex
<code>\Umathradicalrule</code>	<code>set_math_parameter</code>	12	luatex
<code>\Umathradicalvariant</code>	<code>set_math_parameter</code>	125	luatex
<code>\Umathradicalvgap</code>	<code>set_math_parameter</code>	13	luatex
<code>\Umathrelbinspacing</code>	<code>set_math_parameter</code>	78	luatex
<code>\Umathrelclosespacing</code>	<code>set_math_parameter</code>	81	luatex
<code>\Umathrelinnerspacing</code>	<code>set_math_parameter</code>	83	luatex
<code>\Umathrelopenspacing</code>	<code>set_math_parameter</code>	80	luatex
<code>\Umathrelopspacing</code>	<code>set_math_parameter</code>	77	luatex
<code>\Umathrelordspacing</code>	<code>set_math_parameter</code>	76	luatex
<code>\Umathrelpunctspacing</code>	<code>set_math_parameter</code>	82	luatex
<code>\Umathrelrelspacing</code>	<code>set_math_parameter</code>	79	luatex
<code>\Umathskewedfractionhgap</code>	<code>set_math_parameter</code>	26	luatex
<code>\Umathskewedfractionvgap</code>	<code>set_math_parameter</code>	27	luatex
<code>\Umathspaceafterscript</code>	<code>set_math_parameter</code>	50	luatex
<code>\Umathspacebeforescript</code>	<code>set_math_parameter</code>	49	luatex
<code>\Umathspacingmode</code>	<code>set_math_parameter</code>	3	luatex
<code>\Umathstackdenomdown</code>	<code>set_math_parameter</code>	19	luatex
<code>\Umathstacknumup</code>	<code>set_math_parameter</code>	18	luatex
<code>\Umathstackvariant</code>	<code>set_math_parameter</code>	135	luatex
<code>\Umathstackvgap</code>	<code>set_math_parameter</code>	17	luatex
<code>\Umathsubscriptvariant</code>	<code>set_math_parameter</code>	134	luatex
<code>\Umathsubshiftdown</code>	<code>set_math_parameter</code>	42	luatex
<code>\Umathsubshiftdrop</code>	<code>set_math_parameter</code>	40	luatex
<code>\Umathsubsupshiftdown</code>	<code>set_math_parameter</code>	43	luatex
<code>\Umathsubsupvgap</code>	<code>set_math_parameter</code>	48	luatex
<code>\Umathsubtopmax</code>	<code>set_math_parameter</code>	44	luatex
<code>\Umathsupbottommin</code>	<code>set_math_parameter</code>	46	luatex
<code>\Umathsuperscriptvariant</code>	<code>set_math_parameter</code>	133	luatex
<code>\Umathsupshiftdrop</code>	<code>set_math_parameter</code>	41	luatex
<code>\Umathsupshiftup</code>	<code>set_math_parameter</code>	45	luatex
<code>\Umathsupsubbottommax</code>	<code>set_math_parameter</code>	47	luatex
<code>\Umathtopaccentvariant</code>	<code>set_math_parameter</code>	128	luatex
<code>\Umathunderbarkern</code>	<code>set_math_parameter</code>	8	luatex
<code>\Umathunderbarrule</code>	<code>set_math_parameter</code>	9	luatex
<code>\Umathunderbarvgap</code>	<code>set_math_parameter</code>	10	luatex
<code>\Umathunderdelimiterbgap</code>	<code>set_math_parameter</code>	37	luatex
<code>\Umathunderdelimitervariant</code>	<code>set_math_parameter</code>	119	luatex
<code>\Umathunderdelimitervgap</code>	<code>set_math_parameter</code>	36	luatex
<code>\Umathunderlinevariant</code>	<code>set_math_parameter</code>	117	luatex



<code>\Umathvextensiblevariant</code>	<code>set_math_parameter</code>	123	luatex
<code>\Umathvoid</code>	<code>math_modifier</code>	9	luatex
<code>\Umiddle</code>	<code>math_fence</code>	6	luatex
<code>\Unosubprescript</code>	<code>math_script</code>	7	luatex
<code>\Unosubscript</code>	<code>math_script</code>	5	luatex
<code>\Unosuperprescript</code>	<code>math_script</code>	8	luatex
<code>\Unosuperscript</code>	<code>math_script</code>	6	luatex
<code>\Uover</code>	<code>math_fraction</code>	5	luatex
<code>\Uoverdelimitter</code>	<code>math_radical</code>	4	luatex
<code>\Uoverwithdelims</code>	<code>math_fraction</code>	13	luatex
<code>\Uradical</code>	<code>math_radical</code>	1	luatex
<code>\Uright</code>	<code>math_fence</code>	7	luatex
<code>\Uroot</code>	<code>math_radical</code>	2	luatex
<code>\Uskewed</code>	<code>math_fraction</code>	3	luatex
<code>\Uskewedwithdelims</code>	<code>math_fraction</code>	11	luatex
<code>\Ustack</code>	<code>math_choice</code>	1	luatex
<code>\Ustartdisplaymath</code>	<code>math_shift_cs</code>	2	luatex
<code>\Ustartmath</code>	<code>math_shift_cs</code>	0	luatex
<code>\Ustopdisplaymath</code>	<code>math_shift_cs</code>	3	luatex
<code>\Ustopmath</code>	<code>math_shift_cs</code>	1	luatex
<code>\Ustyle</code>	<code>math_style</code>	8	luatex
<code>\Usubprescript</code>	<code>math_script</code>	4	luatex
<code>\Usubscript</code>	<code>math_script</code>	1	luatex
<code>\Usuperprescript</code>	<code>math_script</code>	3	luatex
<code>\Usuperscript</code>	<code>math_script</code>	2	luatex
<code>\Uunderdelimitter</code>	<code>math_radical</code>	3	luatex
<code>\Uvextensible</code>	<code>math_fence</code>	4	luatex
<code>\above</code>	<code>math_fraction</code>	0	tex
<code>\abovedisplayshortskip</code>	<code>internal_glue</code>	5	tex
<code>\abovedisplayskip</code>	<code>internal_glue</code>	3	tex
<code>\abovewithdelims</code>	<code>math_fraction</code>	8	tex
<code>\accent</code>	<code>accent</code>	0	tex
<code>\adjdemerits</code>	<code>internal_int</code>	16	tex
<code>\adjustspacing</code>	<code>internal_int</code>	82	luatex
<code>\adjustspacingshrink</code>	<code>internal_int</code>	85	luatex
<code>\adjustspacingstep</code>	<code>internal_int</code>	83	luatex
<code>\adjustspacingstretch</code>	<code>internal_int</code>	84	luatex
<code>\advance</code>	<code>arithmic</code>	0	tex
<code>\afterassigned</code>	<code>after_something</code>	4	luatex
<code>\afterassignment</code>	<code>after_something</code>	1	tex
<code>\aftergroup</code>	<code>after_something</code>	0	tex
<code>\aftergrouped</code>	<code>after_something</code>	3	luatex
<code>\aliased</code>	<code>prefix</code>	10	luatex
<code>\alignmark</code>	<code>parameter</code>	0	luatex
<code>\aligntab</code>	<code>alignment_tab</code>	0	luatex
<code>\atendofgroup</code>	<code>after_something</code>	2	luatex



<code>\atendofgrouped</code>	<code>after_something</code>	5	luatex
<code>\atop</code>	<code>math_fraction</code>	2	tex
<code>\atopwithdelims</code>	<code>math_fraction</code>	10	tex
<code>\attribute</code>	<code>register</code>	1	luatex
<code>\attributedef</code>	<code>shorthand_def</code>	5	luatex
<code>\automaticdiscretionary</code>	<code>discretionary</code>	2	luatex
<code>\automatichyphenpenalty</code>	<code>internal_int</code>	109	luatex
<code>\automigrationmode</code>	<code>internal_int</code>	113	luatex
<code>\badness</code>	<code>some_item</code>	6	tex
<code>\baselineskip</code>	<code>internal_glue</code>	1	tex
<code>\batchmode</code>	<code>set_interaction</code>	0	tex
<code>\begincsname</code>	<code>cs_name</code>	2	luatex
<code>\begingroup</code>	<code>begin_group</code>	0	tex
<code>\beginlocalcontrol</code>	<code>begin_local</code>	0	luatex
<code>\beginsimplegroup</code>	<code>begin_group</code>	1	tex
<code>\belowdisplaysshortskip</code>	<code>internal_glue</code>	6	tex
<code>\belowdisplayskip</code>	<code>internal_glue</code>	4	tex
<code>\binoppenalty</code>	<code>internal_int</code>	9	tex
<code>\botmark</code>	<code>get_mark</code>	2	tex
<code>\botmarks</code>	<code>get_mark</code>	7	etex
<code>\boundary</code>	<code>boundary</code>	1	luatex
<code>\box</code>	<code>make_box</code>	0	tex
<code>\boxattribute</code>	<code>set_box_property</code>	10	luatex
<code>\boxdirection</code>	<code>set_box_property</code>	3	luatex
<code>\boxmaxdepth</code>	<code>internal_dimen</code>	7	tex
<code>\boxorientation</code>	<code>set_box_property</code>	4	luatex
<code>\boxtotal</code>	<code>set_box_property</code>	9	luatex
<code>\boxxmove</code>	<code>set_box_property</code>	7	luatex
<code>\boxxoffset</code>	<code>set_box_property</code>	5	luatex
<code>\boxymove</code>	<code>set_box_property</code>	8	luatex
<code>\boxyoffset</code>	<code>set_box_property</code>	6	luatex
<code>\brokenpenalty</code>	<code>internal_int</code>	8	tex
<code>\catcode</code>	<code>define_char_code</code>	0	tex
<code>\catcodetable</code>	<code>internal_int</code>	79	luatex
<code>\char</code>	<code>char_number</code>	0	tex
<code>\chardef</code>	<code>shorthand_def</code>	0	tex
<code>\cleaders</code>	<code>special_box</code>	4	tex
<code>\clearmarks</code>	<code>set_mark</code>	2	luatex
<code>\clubpenalties</code>	<code>set_specification</code>	0	etex
<code>\clubpenalty</code>	<code>internal_int</code>	5	tex
<code>\copy</code>	<code>make_box</code>	1	tex
<code>\count</code>	<code>register</code>	0	tex
<code>\countdef</code>	<code>shorthand_def</code>	4	tex
<code>\cr</code>	<code>end_template</code>	4	tex
<code>\crampeddisplaystyle</code>	<code>math_style</code>	1	luatex
<code>\crampedscriptscriptstyle</code>	<code>math_style</code>	7	luatex



<code>\crampedscriptstyle</code>	<code>math_style</code>	5	luatex
<code>\crampedtextstyle</code>	<code>math_style</code>	3	luatex
<code>\crrc</code>	<code>end_template</code>	5	tex
<code>\csname</code>	<code>cs_name</code>	0	tex
<code>\csstring</code>	<code>convert</code>	9	luatex
<code>\currentgrouplevel</code>	<code>some_item</code>	10	etex
<code>\currentgrouptype</code>	<code>some_item</code>	11	etex
<code>\currentifbranch</code>	<code>some_item</code>	14	etex
<code>\currentiflevel</code>	<code>some_item</code>	12	etex
<code>\currentifttype</code>	<code>some_item</code>	13	etex
<code>\day</code>	<code>internal_int</code>	20	tex
<code>\deadcycles</code>	<code>set_page_property</code>	8	tex
<code>\def</code>	<code>def</code>	1	tex
<code>\defaulthyphenchar</code>	<code>internal_int</code>	55	tex
<code>\defaultskewchar</code>	<code>internal_int</code>	56	tex
<code>\defcsname</code>	<code>def</code>	5	luatex
<code>\delcode</code>	<code>define_char_code</code>	8	tex
<code>\delimiter</code>	<code>delimiter_number</code>	0	tex
<code>\delimiterfactor</code>	<code>internal_int</code>	17	tex
<code>\delimitershortfall</code>	<code>internal_dimen</code>	10	tex
<code>\detokenize</code>	<code>the</code>	3	etex
<code>\dimen</code>	<code>register</code>	2	tex
<code>\dimendef</code>	<code>shorthand_def</code>	6	tex
<code>\dimensiondef</code>	<code>shorthand_def</code>	12	luatex
<code>\dimexpr</code>	<code>some_item</code>	41	etex
<code>\directlua</code>	<code>convert</code>	4	luatex
<code>\discretionary</code>	<code>discretionary</code>	0	tex
<code>\displayindent</code>	<code>internal_dimen</code>	15	tex
<code>\displaylimits</code>	<code>math_modifier</code>	0	tex
<code>\displaystyle</code>	<code>math_style</code>	0	tex
<code>\displaywidowpenalties</code>	<code>set_specification</code>	0	etex
<code>\displaywidowpenalty</code>	<code>internal_int</code>	7	tex
<code>\displaywidth</code>	<code>internal_dimen</code>	14	tex
<code>\divide</code>	<code>arithmic</code>	2	tex
<code>\doublehyphendemerits</code>	<code>internal_int</code>	14	tex
<code>\dp</code>	<code>set_box_property</code>	2	tex
<code>\dump</code>	<code>end_job</code>	1	tex
<code>\edef</code>	<code>def</code>	0	tex
<code>\edefcsname</code>	<code>def</code>	4	luatex
<code>\efcode</code>	<code>set_font_property</code>	4	luatex
<code>\else</code>	<code>if_test</code>	3	tex
<code>\emergencystretch</code>	<code>internal_dimen</code>	18	tex
<code>\end</code>	<code>end_job</code>	0	tex
<code>\endcsname</code>	<code>end_cs_name</code>	0	tex
<code>\endgroup</code>	<code>end_group</code>	0	tex
<code>\endinput</code>	<code>input</code>	1	tex



<code>\endlinechar</code>	<code>internal_int</code>	57	tex
<code>\endlocalcontrol</code>	<code>end_local</code>	0	luatex
<code>\endsimplegroup</code>	<code>end_group</code>	1	tex
<code>\enforced</code>	<code>prefix</code>	12	luatex
<code>\eqno</code>	<code>equation_number</code>	1	tex
<code>\errhelp</code>	<code>internal_toks</code>	9	tex
<code>\errmessage</code>	<code>message</code>	1	tex
<code>\errorcontextlines</code>	<code>internal_int</code>	65	tex
<code>\errorstopmode</code>	<code>set_interaction</code>	3	tex
<code>\escapechar</code>	<code>internal_int</code>	54	tex
<code>\etoksapp</code>	<code>combine_toks</code>	1	luatex
<code>\etokspre</code>	<code>combine_toks</code>	3	luatex
<code>\everycr</code>	<code>internal_toks</code>	7	tex
<code>\everydisplay</code>	<code>internal_toks</code>	3	tex
<code>\everyeof</code>	<code>internal_toks</code>	10	etex
<code>\everyhbox</code>	<code>internal_toks</code>	4	tex
<code>\everyjob</code>	<code>internal_toks</code>	6	tex
<code>\everymath</code>	<code>internal_toks</code>	2	tex
<code>\everypar</code>	<code>internal_toks</code>	1	tex
<code>\everytab</code>	<code>internal_toks</code>	8	luatex
<code>\everyvbox</code>	<code>internal_toks</code>	5	tex
<code>\exceptionpenalty</code>	<code>internal_int</code>	111	luatex
<code>\exhyphenchar</code>	<code>internal_int</code>	81	tex
<code>\exhyphenpenalty</code>	<code>internal_int</code>	4	tex
<code>\expand</code>	<code>expand_after</code>	9	luatex
<code>\expandafter</code>	<code>expand_after</code>	0	tex
<code>\expandafterpars</code>	<code>expand_after</code>	6	luatex
<code>\expandafterspaces</code>	<code>expand_after</code>	5	luatex
<code>\expandcstoken</code>	<code>expand_after</code>	8	luatex
<code>\expanded</code>	<code>convert</code>	7	luatex
<code>\expandtoken</code>	<code>expand_after</code>	7	luatex
<code>\explicitdiscretionary</code>	<code>discretionary</code>	1	luatex
<code>\explicitthyphenpenalty</code>	<code>internal_int</code>	110	luatex
<code>\fam</code>	<code>internal_int</code>	53	tex
<code>\fi</code>	<code>if_test</code>	2	tex
<code>\finalhyphendemerits</code>	<code>internal_int</code>	15	tex
<code>\firstmark</code>	<code>get_mark</code>	1	tex
<code>\firstmarks</code>	<code>get_mark</code>	6	etex
<code>\firstvalidlanguage</code>	<code>internal_int</code>	108	luatex
<code>\floatingpenalty</code>	<code>internal_int</code>	51	tex
<code>\font</code>	<code>define_font</code>	0	tex
<code>\fontchardp</code>	<code>some_item</code>	20	etex
<code>\fontcharht</code>	<code>some_item</code>	19	etex
<code>\fontcharic</code>	<code>some_item</code>	21	etex
<code>\fontcharwd</code>	<code>some_item</code>	18	etex
<code>\fontdimen</code>	<code>set_font_property</code>	5	tex



<code>\fontid</code>	<code>some_item</code>	17	luatex
<code>\fontname</code>	<code>convert</code>	16	tex
<code>\fontspecifiedname</code>	<code>convert</code>	17	tex
<code>\fontspecifiedsize</code>	<code>some_item</code>	22	luatex
<code>\formatname</code>	<code>convert</code>	19	luatex
<code>\frozen</code>	<code>prefix</code>	0	luatex
<code>\futuredef</code>	<code>let</code>	3	luatex
<code>\futureexpand</code>	<code>expand_after</code>	2	luatex
<code>\futureexpandis</code>	<code>expand_after</code>	3	luatex
<code>\futureexpandisap</code>	<code>expand_after</code>	4	luatex
<code>\futurelet</code>	<code>let</code>	2	tex
<code>\gdef</code>	<code>def</code>	3	tex
<code>\gdefcsname</code>	<code>def</code>	7	luatex
<code>\gleaders</code>	<code>special_box</code>	6	luatex
<code>\glet</code>	<code>let</code>	0	luatex
<code>\gletcsname</code>	<code>let</code>	11	luatex
<code>\glettonothing</code>	<code>let</code>	13	luatex
<code>\global</code>	<code>prefix</code>	6	tex
<code>\globaldefs</code>	<code>internal_int</code>	52	tex
<code>\glueexpr</code>	<code>some_item</code>	42	etex
<code>\glueshrink</code>	<code>some_item</code>	37	etex
<code>\glueshrinkorder</code>	<code>some_item</code>	16	etex
<code>\gluespecdef</code>	<code>shorthand_def</code>	13	luatex
<code>\gluestretch</code>	<code>some_item</code>	36	etex
<code>\gluestretchorder</code>	<code>some_item</code>	15	etex
<code>\gluetomu</code>	<code>some_item</code>	39	etex
<code>\glyph</code>	<code>char_number</code>	1	tex
<code>\glyphdatafield</code>	<code>internal_int</code>	72	luatex
<code>\glyphoptions</code>	<code>internal_int</code>	75	luatex
<code>\glyphscale</code>	<code>internal_int</code>	69	luatex
<code>\glyphscriptfield</code>	<code>internal_int</code>	74	luatex
<code>\glyphscriptscale</code>	<code>internal_int</code>	77	luatex
<code>\glyphscriptscriptscale</code>	<code>internal_int</code>	78	luatex
<code>\glyphstatefield</code>	<code>internal_int</code>	73	luatex
<code>\glyphtextscale</code>	<code>internal_int</code>	76	luatex
<code>\glyphxoffset</code>	<code>internal_dimen</code>	19	luatex
<code>\glyphxscale</code>	<code>internal_int</code>	70	luatex
<code>\glyphyoffset</code>	<code>internal_dimen</code>	20	luatex
<code>\glyphyscale</code>	<code>internal_int</code>	71	luatex
<code>\gtoksapp</code>	<code>combine_toks</code>	4	luatex
<code>\gtokspre</code>	<code>combine_toks</code>	6	luatex
<code>\halign</code>	<code>halign</code>	0	tex
<code>\hangafter</code>	<code>internal_int</code>	50	tex
<code>\hangindent</code>	<code>internal_dimen</code>	17	tex
<code>\hbadness</code>	<code>internal_int</code>	26	tex
<code>\hbox</code>	<code>make_box</code>	10	tex



<code>\hccode</code>	<code>define_char_code</code>	4	luatex
<code>\hfil</code>	<code>hskip</code>	0	tex
<code>\hfill</code>	<code>hskip</code>	1	tex
<code>\hfilneg</code>	<code>hskip</code>	3	tex
<code>\hfuzz</code>	<code>internal_dimen</code>	8	tex
<code>\hjcode</code>	<code>hyphenation</code>	7	luatex
<code>\holdinginserts</code>	<code>internal_int</code>	64	tex
<code>\hpack</code>	<code>make_box</code>	7	luatex
<code>\hrule</code>	<code>hrule</code>	0	tex
<code>\hsize</code>	<code>internal_dimen</code>	3	tex
<code>\hskip</code>	<code>hskip</code>	4	tex
<code>\hss</code>	<code>hskip</code>	2	tex
<code>\ht</code>	<code>set_box_property</code>	1	tex
<code>\hyphenation</code>	<code>hyphenation</code>	0	tex
<code>\hyphenationmin</code>	<code>hyphenation</code>	6	luatex
<code>\hyphenationmode</code>	<code>internal_int</code>	61	luatex
<code>\hyphenchar</code>	<code>set_font_property</code>	0	tex
<code>\hyphenpenalty</code>	<code>internal_int</code>	3	tex
<code>\if</code>	<code>if_test</code>	7	tex
<code>\ifabsdim</code>	<code>if_test</code>	11	luatex
<code>\ifabsnum</code>	<code>if_test</code>	9	luatex
<code>\ifarguments</code>	<code>if_test</code>	44	luatex
<code>\ifboolean</code>	<code>if_test</code>	41	luatex
<code>\ifcase</code>	<code>if_test</code>	32	tex
<code>\ifcat</code>	<code>if_test</code>	8	tex
<code>\ifchkdim</code>	<code>if_test</code>	29	luatex
<code>\ifchknum</code>	<code>if_test</code>	26	luatex
<code>\ifcmpdim</code>	<code>if_test</code>	31	luatex
<code>\ifcmpnum</code>	<code>if_test</code>	28	luatex
<code>\ifcondition</code>	<code>if_test</code>	37	luatex
<code>\ifcsname</code>	<code>if_test</code>	34	etex
<code>\ifcstok</code>	<code>if_test</code>	22	luatex
<code>\ifdefined</code>	<code>if_test</code>	33	etex
<code>\ifdim</code>	<code>if_test</code>	12	tex
<code>\ifdimval</code>	<code>if_test</code>	30	luatex
<code>\ifempty</code>	<code>if_test</code>	39	luatex
<code>\iffalse</code>	<code>if_test</code>	25	tex
<code>\ifflags</code>	<code>if_test</code>	38	luatex
<code>\iffontchar</code>	<code>if_test</code>	36	etex
<code>\ifhastok</code>	<code>if_test</code>	47	luatex
<code>\ifhastoks</code>	<code>if_test</code>	48	luatex
<code>\ifhasxtoks</code>	<code>if_test</code>	49	luatex
<code>\ifhbox</code>	<code>if_test</code>	19	tex
<code>\ifhmode</code>	<code>if_test</code>	15	tex
<code>\ifincsname</code>	<code>if_test</code>	35	luatex
<code>\ifinner</code>	<code>if_test</code>	17	tex



<code>\ifinsert</code>	<code>if_test</code>	50	luatex
<code>\ifmathparameter</code>	<code>if_test</code>	42	luatex
<code>\ifmathstyle</code>	<code>if_test</code>	43	luatex
<code>\ifmmode</code>	<code>if_test</code>	16	tex
<code>\ifnum</code>	<code>if_test</code>	10	tex
<code>\ifnumval</code>	<code>if_test</code>	27	luatex
<code>\ifodd</code>	<code>if_test</code>	13	tex
<code>\ifparameter</code>	<code>if_test</code>	46	luatex
<code>\ifparameters</code>	<code>if_test</code>	45	luatex
<code>\ifrelax</code>	<code>if_test</code>	40	luatex
<code>\iftok</code>	<code>if_test</code>	21	luatex
<code>\iftrue</code>	<code>if_test</code>	24	tex
<code>\ifvbox</code>	<code>if_test</code>	20	tex
<code>\ifvmode</code>	<code>if_test</code>	14	tex
<code>\ifvoid</code>	<code>if_test</code>	18	tex
<code>\ifx</code>	<code>if_test</code>	23	tex
<code>\ignorearguments</code>	<code>ignore_something</code>	2	luatex
<code>\ignorepars</code>	<code>ignore_something</code>	1	luatex
<code>\ignorespaces</code>	<code>ignore_something</code>	0	tex
<code>\immediate</code>	<code>prefix</code>	11	luatex
<code>\immutable</code>	<code>prefix</code>	2	luatex
<code>\indent</code>	<code>begin_paragraph</code>	1	tex
<code>\initcatcodetable</code>	<code>catcode_table</code>	1	luatex
<code>\input</code>	<code>input</code>	0	tex
<code>\inputlineno</code>	<code>some_item</code>	5	tex
<code>\insert</code>	<code>insert</code>	0	tex
<code>\insertbox</code>	<code>make_box</code>	11	luatex
<code>\insertcopy</code>	<code>make_box</code>	12	luatex
<code>\insertdepth</code>	<code>set_page_property</code>	15	luatex
<code>\insertdistance</code>	<code>set_page_property</code>	11	luatex
<code>\insertheight</code>	<code>set_page_property</code>	14	luatex
<code>\insertheights</code>	<code>set_page_property</code>	10	luatex
<code>\insertlimit</code>	<code>set_page_property</code>	13	luatex
<code>\insertmode</code>	<code>set_auxiliary</code>	4	luatex
<code>\insertmultiplier</code>	<code>set_page_property</code>	12	luatex
<code>\insertpenalties</code>	<code>set_page_property</code>	9	tex
<code>\insertprogress</code>	<code>some_item</code>	30	luatex
<code>\insertunbox</code>	<code>un_vbox</code>	11	luatex
<code>\insertuncopy</code>	<code>un_vbox</code>	12	luatex
<code>\insertwidth</code>	<code>set_page_property</code>	16	luatex
<code>\instance</code>	<code>prefix</code>	5	luatex
<code>\integerdef</code>	<code>shorthand_def</code>	11	luatex
<code>\interactionmode</code>	<code>set_auxiliary</code>	3	etex
<code>\interlinepenalties</code>	<code>set_specification</code>	0	etex
<code>\interlinepenalty</code>	<code>internal_int</code>	13	tex
<code>\jobname</code>	<code>convert</code>	18	tex



<code>\kern</code>	<code>kern</code>	0	<code>tex</code>
<code>\language</code>	<code>internal_int</code>	59	<code>tex</code>
<code>\lastarguments</code>	<code>some_item</code>	28	<code>luatex</code>
<code>\lastbox</code>	<code>make_box</code>	3	<code>tex</code>
<code>\lastchkdir</code>	<code>some_item</code>	45	<code>etex</code>
<code>\lastchknum</code>	<code>some_item</code>	44	<code>etex</code>
<code>\lastkern</code>	<code>some_item</code>	1	<code>tex</code>
<code>\lastlinefit</code>	<code>internal_int</code>	88	<code>etex</code>
<code>\lastnamedcs</code>	<code>cs_name</code>	1	<code>luatex</code>
<code>\lastnodesubtype</code>	<code>some_item</code>	4	<code>luatex</code>
<code>\lastnodetype</code>	<code>some_item</code>	3	<code>etex</code>
<code>\lastpenalty</code>	<code>some_item</code>	0	<code>tex</code>
<code>\lastskip</code>	<code>some_item</code>	2	<code>tex</code>
<code>\lccode</code>	<code>define_char_code</code>	1	<code>tex</code>
<code>\leaders</code>	<code>special_box</code>	3	<code>tex</code>
<code>\left</code>	<code>math_fence</code>	1	<code>tex</code>
<code>\lefthyphenmin</code>	<code>internal_int</code>	62	<code>tex</code>
<code>\leftmarginkern</code>	<code>some_item</code>	31	<code>luatex</code>
<code>\leftskip</code>	<code>internal_glue</code>	7	<code>tex</code>
<code>\leqno</code>	<code>equation_number</code>	0	<code>tex</code>
<code>\let</code>	<code>let</code>	1	<code>tex</code>
<code>\letcharcode</code>	<code>let</code>	4	<code>luatex</code>
<code>\letcsname</code>	<code>let</code>	10	<code>luatex</code>
<code>\letfrozen</code>	<code>let</code>	8	<code>luatex</code>
<code>\letprotected</code>	<code>let</code>	6	<code>luatex</code>
<code>\lettonothing</code>	<code>let</code>	12	<code>luatex</code>
<code>\limits</code>	<code>math_modifier</code>	1	<code>tex</code>
<code>\linedirection</code>	<code>internal_int</code>	119	<code>luatex</code>
<code>\linepar</code>	<code>undefined_cs</code>	0	<code>luatex</code>
<code>\linepenalty</code>	<code>internal_int</code>	2	<code>tex</code>
<code>\lineskip</code>	<code>internal_glue</code>	0	<code>tex</code>
<code>\lineskiplimit</code>	<code>internal_dimen</code>	2	<code>tex</code>
<code>\localbrokenpenalty</code>	<code>internal_int</code>	67	<code>luatex</code>
<code>\localcontrol</code>	<code>begin_local</code>	1	<code>luatex</code>
<code>\localcontrolled</code>	<code>begin_local</code>	2	<code>luatex</code>
<code>\localinterlinepenalty</code>	<code>internal_int</code>	66	<code>luatex</code>
<code>\localleftbox</code>	<code>special_box</code>	1	<code>luatex</code>
<code>\localrightbox</code>	<code>special_box</code>	2	<code>luatex</code>
<code>\long</code>	<code>prefix</code>	14	<code>tex</code>
<code>\looseness</code>	<code>internal_int</code>	18	<code>tex</code>
<code>\lower</code>	<code>vmove</code>	0	<code>tex</code>
<code>\lowercase</code>	<code>case_shift</code>	0	<code>tex</code>
<code>\lpcode</code>	<code>set_font_property</code>	2	<code>luatex</code>
<code>\luabytecode</code>	<code>convert</code>	6	<code>luatex</code>
<code>\luabytecodecall</code>	<code>lua_function_call</code>	1	<code>luatex</code>
<code>\luacopyinputnodes</code>	<code>internal_int</code>	112	<code>luatex</code>



<code>\luaedef</code>	<code>shorthand_def</code>	10	luatex
<code>\luaescapestring</code>	<code>convert</code>	15	luatex
<code>\luafunction</code>	<code>convert</code>	5	luatex
<code>\luafunctioncall</code>	<code>lua_function_call</code>	0	luatex
<code>\luatexbanner</code>	<code>convert</code>	20	luatex
<code>\luatexrevision</code>	<code>some_item</code>	9	luatex
<code>\luatexversion</code>	<code>some_item</code>	8	luatex
<code>\mark</code>	<code>set_mark</code>	0	tex
<code>\marks</code>	<code>set_mark</code>	1	etex
<code>\mathaccent</code>	<code>math_accent</code>	0	tex
<code>\mathbin</code>	<code>math_component</code>	2	tex
<code>\mathchar</code>	<code>math_char_number</code>	0	tex
<code>\mathchardef</code>	<code>shorthand_def</code>	1	tex
<code>\mathchoice</code>	<code>math_choice</code>	0	tex
<code>\mathclose</code>	<code>math_component</code>	5	tex
<code>\mathcode</code>	<code>define_char_code</code>	5	tex
<code>\mathdelimitersmode</code>	<code>internal_int</code>	101	luatex
<code>\mathdirection</code>	<code>internal_int</code>	118	luatex
<code>\mathdisplayskipmode</code>	<code>internal_int</code>	92	luatex
<code>\matheqnogapstep</code>	<code>internal_int</code>	91	luatex
<code>\mathflattenmode</code>	<code>internal_int</code>	103	luatex
<code>\mathinner</code>	<code>math_component</code>	7	tex
<code>\mathitalicsmode</code>	<code>internal_int</code>	99	luatex
<code>\mathnolimitsmode</code>	<code>internal_int</code>	96	luatex
<code>\mathop</code>	<code>math_component</code>	1	tex
<code>\mathopen</code>	<code>math_component</code>	4	tex
<code>\mathord</code>	<code>math_component</code>	0	tex
<code>\mathpenaltiesmode</code>	<code>internal_int</code>	100	luatex
<code>\mathpunct</code>	<code>math_component</code>	6	tex
<code>\mathrel</code>	<code>math_component</code>	3	tex
<code>\mathrulesfam</code>	<code>internal_int</code>	98	luatex
<code>\mathrulesmode</code>	<code>internal_int</code>	97	luatex
<code>\mathrulethicknessmode</code>	<code>internal_int</code>	102	luatex
<code>\mathscale</code>	<code>some_item</code>	23	luatex
<code>\mathscriptboxmode</code>	<code>internal_int</code>	94	luatex
<code>\mathscriptcharmode</code>	<code>internal_int</code>	95	luatex
<code>\mathscriptsmode</code>	<code>internal_int</code>	93	luatex
<code>\mathstyle</code>	<code>some_item</code>	24	luatex
<code>\mathsurround</code>	<code>internal_dimen</code>	1	tex
<code>\mathsurroundmode</code>	<code>internal_int</code>	104	luatex
<code>\mathsurroundskip</code>	<code>internal_glue</code>	16	luatex
<code>\maxdeadcycles</code>	<code>internal_int</code>	49	tex
<code>\maxdepth</code>	<code>internal_dimen</code>	5	tex
<code>\meaning</code>	<code>convert</code>	11	tex
<code>\meaningfull</code>	<code>convert</code>	12	tex
<code>\meaningless</code>	<code>convert</code>	13	tex



<code>\medmuskip</code>	<code>internal_mu_glue</code>	2	tex
<code>\message</code>	<code>message</code>	0	tex
<code>\middle</code>	<code>math_fence</code>	2	tex
<code>\mkern</code>	<code>mkern</code>	0	tex
<code>\month</code>	<code>internal_int</code>	21	tex
<code>\moveleft</code>	<code>hmove</code>	1	tex
<code>\moveright</code>	<code>hmove</code>	0	tex
<code>\mskip</code>	<code>mskip</code>	0	tex
<code>\muexpr</code>	<code>some_item</code>	43	etex
<code>\mugluespecdef</code>	<code>shorthand_def</code>	14	luatex
<code>\multiply</code>	<code>arithmic</code>	1	tex
<code>\muskip</code>	<code>register</code>	4	tex
<code>\muskipdef</code>	<code>shorthand_def</code>	8	tex
<code>\mutable</code>	<code>prefix</code>	3	luatex
<code>\mutoglua</code>	<code>some_item</code>	38	etex
<code>\newlinechar</code>	<code>internal_int</code>	58	tex
<code>\noalign</code>	<code>end_template</code>	3	tex
<code>\noaligned</code>	<code>prefix</code>	4	luatex
<code>\noboundary</code>	<code>boundary</code>	0	luatex
<code>\noexpand</code>	<code>no_expand</code>	0	tex
<code>\nohrule</code>	<code>hrule</code>	1	luatex
<code>\noindent</code>	<code>begin_paragraph</code>	0	tex
<code>\nolimits</code>	<code>math_modifier</code>	2	tex
<code>\nonscript</code>	<code>math_script</code>	0	tex
<code>\nonstopmode</code>	<code>set_interaction</code>	1	tex
<code>\norelax</code>	<code>relax</code>	1114113	luatex
<code>\normalizelinemode</code>	<code>internal_int</code>	114	luatex
<code>\nospaces</code>	<code>internal_int</code>	68	luatex
<code>\novrule</code>	<code>vrule</code>	1	luatex
<code>\nulldelimiterspace</code>	<code>internal_dimen</code>	11	tex
<code>\nullfont</code>	<code>set_font</code>	0	tex
<code>\number</code>	<code>convert</code>	0	tex
<code>\numericsscale</code>	<code>some_item</code>	46	etex
<code>\numexpr</code>	<code>some_item</code>	40	etex
<code>\omit</code>	<code>end_template</code>	2	tex
<code>\or</code>	<code>if_test</code>	4	tex
<code>\ordlimits</code>	<code>math_modifier</code>	3	tex
<code>\orelse</code>	<code>if_test</code>	5	luatex
<code>\orunless</code>	<code>if_test</code>	6	luatex
<code>\outer</code>	<code>prefix</code>	15	tex
<code>\output</code>	<code>internal_toks</code>	0	tex
<code>\outputbox</code>	<code>internal_int</code>	80	luatex
<code>\outputpenalty</code>	<code>internal_int</code>	48	tex
<code>\over</code>	<code>math_fraction</code>	1	tex
<code>\overfullrule</code>	<code>internal_dimen</code>	16	tex
<code>\overline</code>	<code>math_component</code>	9	tex



<code>\overloaded</code>	<code>prefix</code>	9	luatex
<code>\overloadmode</code>	<code>internal_int</code>	120	luatex
<code>\overshoot</code>	<code>some_item</code>	7	tex
<code>\overwithdelims</code>	<code>math_fraction</code>	9	tex
<code>\pagedepth</code>	<code>set_page_property</code>	7	tex
<code>\pagediscards</code>	<code>un_vbox</code>	3	etex
<code>\pagefilllstretch</code>	<code>set_page_property</code>	5	tex
<code>\pagefillstretch</code>	<code>set_page_property</code>	4	tex
<code>\pagefilstretch</code>	<code>set_page_property</code>	3	tex
<code>\pagegoal</code>	<code>set_page_property</code>	0	tex
<code>\pageshrink</code>	<code>set_page_property</code>	6	tex
<code>\pagestretch</code>	<code>set_page_property</code>	2	tex
<code>\pagetotal</code>	<code>set_page_property</code>	1	tex
<code>\par</code>	<code>end_paragraph</code>	1114112	tex
<code>\parametercount</code>	<code>some_item</code>	29	luatex
<code>\parattr</code>	<code>begin_paragraph</code>	5	luatex
<code>\pardirection</code>	<code>internal_int</code>	116	luatex
<code>\parfillleftskip</code>	<code>internal_glue</code>	14	tex
<code>\parfillskip</code>	<code>internal_glue</code>	15	tex
<code>\parindent</code>	<code>internal_dimen</code>	0	tex
<code>\parshape</code>	<code>set_specification</code>	0	tex
<code>\parshapedimen</code>	<code>some_item</code>	35	etex
<code>\parshapeindent</code>	<code>some_item</code>	34	etex
<code>\parshapelength</code>	<code>some_item</code>	33	etex
<code>\parskip</code>	<code>internal_glue</code>	2	tex
<code>\patterns</code>	<code>hyphenation</code>	1	tex
<code>\pausing</code>	<code>internal_int</code>	28	tex
<code>\penalty</code>	<code>penalty</code>	0	tex
<code>\permanent</code>	<code>prefix</code>	1	luatex
<code>\postdisplaypenalty</code>	<code>internal_int</code>	12	tex
<code>\postexhyphenchar</code>	<code>hyphenation</code>	5	luatex
<code>\postthyphenchar</code>	<code>hyphenation</code>	3	luatex
<code>\prebinoppenalty</code>	<code>internal_int</code>	106	luatex
<code>\predisplaydirection</code>	<code>internal_int</code>	87	etex
<code>\predisplaygapfactor</code>	<code>internal_int</code>	105	luatex
<code>\predisplaypenalty</code>	<code>internal_int</code>	11	tex
<code>\predisplaysize</code>	<code>internal_dimen</code>	13	tex
<code>\preexhyphenchar</code>	<code>hyphenation</code>	4	luatex
<code>\prehyphenchar</code>	<code>hyphenation</code>	2	luatex
<code>\prerelpenalty</code>	<code>internal_int</code>	107	luatex
<code>\pretolerance</code>	<code>internal_int</code>	0	tex
<code>\prevdepth</code>	<code>set_auxiliary</code>	1	tex
<code>\prevgraf</code>	<code>set_auxiliary</code>	2	tex
<code>\protected</code>	<code>prefix</code>	8	etex
<code>\protrudechars</code>	<code>internal_int</code>	86	luatex
<code>\protrusionboundary</code>	<code>boundary</code>	2	luatex



<code>\pxdimen</code>	<code>internal_dimen</code>	21	luatex
<code>\quitvmode</code>	<code>begin_paragraph</code>	2	luatex
<code>\radical</code>	<code>math_radical</code>	0	tex
<code>\raise</code>	<code>vmove</code>	1	tex
<code>\relax</code>	<code>relax</code>	1114112	tex
<code>\relpenalty</code>	<code>internal_int</code>	10	tex
<code>\right</code>	<code>math_fence</code>	3	tex
<code>\righthyphenmin</code>	<code>internal_int</code>	63	tex
<code>\rightmarginkern</code>	<code>some_item</code>	32	luatex
<code>\rightskip</code>	<code>internal_glue</code>	8	tex
<code>\romannumeral</code>	<code>convert</code>	10	tex
<code>\rptcode</code>	<code>set_font_property</code>	3	luatex
<code>\savecatcodetable</code>	<code>catcode_table</code>	0	luatex
<code>\savingshyphcodes</code>	<code>internal_int</code>	90	etex
<code>\savingsvdiscards</code>	<code>internal_int</code>	89	etex
<code>\scaledfontdimen</code>	<code>set_font_property</code>	6	tex
<code>\scantextokens</code>	<code>input</code>	3	luatex
<code>\scantokens</code>	<code>input</code>	2	etex
<code>\scriptfont</code>	<code>define_family</code>	1	tex
<code>\scriptscriptfont</code>	<code>define_family</code>	2	tex
<code>\scriptscriptstyle</code>	<code>math_style</code>	6	tex
<code>\scriptspace</code>	<code>internal_dimen</code>	12	tex
<code>\scriptstyle</code>	<code>math_style</code>	4	tex
<code>\scrollmode</code>	<code>set_interaction</code>	2	tex
<code>\setbox</code>	<code>set_box</code>	0	tex
<code>\setfontid</code>	<code>internal_int</code>	60	luatex
<code>\setlanguage</code>	<code>internal_int</code>	59	tex
<code>\sfcode</code>	<code>define_char_code</code>	3	tex
<code>\shipout</code>	<code>special_box</code>	0	tex
<code>\show</code>	<code>xray</code>	0	tex
<code>\showbox</code>	<code>xray</code>	1	tex
<code>\showboxbreadth</code>	<code>internal_int</code>	23	tex
<code>\showboxdepth</code>	<code>internal_int</code>	24	tex
<code>\showgroups</code>	<code>xray</code>	4	etex
<code>\showifs</code>	<code>xray</code>	6	etex
<code>\showlists</code>	<code>xray</code>	3	tex
<code>\shownodedetails</code>	<code>internal_int</code>	25	tex
<code>\showthe</code>	<code>xray</code>	2	tex
<code>\showtokens</code>	<code>xray</code>	5	etex
<code>\skewchar</code>	<code>set_font_property</code>	1	tex
<code>\skip</code>	<code>register</code>	3	tex
<code>\skipdef</code>	<code>shorthand_def</code>	7	tex
<code>\snapshotpar</code>	<code>begin_paragraph</code>	4	luatex
<code>\spacefactor</code>	<code>set_auxiliary</code>	0	tex
<code>\spaceskip</code>	<code>internal_glue</code>	12	tex
<code>\span</code>	<code>end_template</code>	1	tex



<code>\splitbotmark</code>	<code>get_mark</code>	4	tex
<code>\splitbotmarks</code>	<code>get_mark</code>	9	etex
<code>\splitdiscards</code>	<code>un_vbox</code>	4	etex
<code>\splitfirstmark</code>	<code>get_mark</code>	3	tex
<code>\splitfirstmarks</code>	<code>get_mark</code>	8	etex
<code>\splitmaxdepth</code>	<code>internal_dimen</code>	6	tex
<code>\splittopskip</code>	<code>internal_glue</code>	10	tex
<code>\string</code>	<code>convert</code>	8	tex
<code>\supmarkmode</code>	<code>internal_int</code>	115	luatex
<code>\swapcsvalues</code>	<code>let</code>	5	luatex
<code>\tabskip</code>	<code>internal_glue</code>	11	tex
<code>\textdirection</code>	<code>internal_int</code>	117	luatex
<code>\textfont</code>	<code>define_family</code>	0	tex
<code>\textstyle</code>	<code>math_style</code>	2	tex
<code>\the</code>	<code>the</code>	0	tex
<code>\thewithoutunit</code>	<code>the</code>	1	luatex
<code>\thewithproperty</code>	<code>the</code>	2	luatex
<code>\thickmuskip</code>	<code>internal_mu_glue</code>	3	tex
<code>\thinmuskip</code>	<code>internal_mu_glue</code>	1	tex
<code>\time</code>	<code>internal_int</code>	19	tex
<code>\todimension</code>	<code>convert</code>	3	tex
<code>\tointeger</code>	<code>convert</code>	1	tex
<code>\tokenized</code>	<code>input</code>	4	luatex
<code>\toks</code>	<code>register</code>	5	tex
<code>\toksapp</code>	<code>combine_toks</code>	0	luatex
<code>\toksdef</code>	<code>shorthand_def</code>	9	tex
<code>\tokspre</code>	<code>combine_toks</code>	2	luatex
<code>\tolerance</code>	<code>internal_int</code>	1	tex
<code>\tolerant</code>	<code>prefix</code>	7	luatex
<code>\topmark</code>	<code>get_mark</code>	0	tex
<code>\topmarks</code>	<code>get_mark</code>	5	etex
<code>\topskip</code>	<code>internal_glue</code>	9	tex
<code>\toscaled</code>	<code>convert</code>	2	tex
<code>\tpack</code>	<code>make_box</code>	5	luatex
<code>\tracingalignments</code>	<code>internal_int</code>	45	etex
<code>\tracingassigns</code>	<code>internal_int</code>	39	etex
<code>\tracingcommands</code>	<code>internal_int</code>	36	tex
<code>\tracingfonts</code>	<code>internal_int</code>	38	luatex
<code>\tracinggroups</code>	<code>internal_int</code>	40	etex
<code>\tracinghyphenation</code>	<code>internal_int</code>	46	luatex
<code>\tracingifs</code>	<code>internal_int</code>	41	etex
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Statistics

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used	filesize	version	filename
2	988.684	5.000	cammath.ttf
1	927.280	5.020	cambria.ttf
1	163.452	1.802	LucidaBrightMath0T-Demi.otf
1	348.296	1.802	LucidaBrightMath0T.otf
1	73.284	1.801	LucidaBright0T.otf
2	733.500	1.958	latinmodern-math.otf
2	64.684	2.004	lmmono10-regular.otf
1	64.160	2.004	lmmonoltcond10-regular.otf
1	111.536	2.004	lmroman10-regular.otf
3	525.008	1.106	texgyredejavu-math.otf
2	601.220	1.632	texgyrepagella-math.otf
1	218.100	2.501	texgyrepagella-regular.otf
1	693.876	2.340	DejaVuSans-Bold.ttf
1	741.536	2.340	DejaVuSans.ttf
1	318.392	2.340	DejaVuSansMono-Bold.ttf
1	245.948	2.340	DejaVuSansMono-Oblique.ttf
1	335.068	2.340	DejaVuSansMono.ttf
2	345.364	2.340	DejaVuSerif-Bold.ttf
1	336.884	2.340	DejaVuSerif-BoldItalic.ttf
1	343.388	2.340	DejaVuSerif-Italic.ttf
1	367.260	2.340	DejaVuSerif.ttf
28	8.546.920		21 files loaded



