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Introduction

This is the reference manual of Lua\TeX. We don’t claim it is complete and we assume that the reader knows about \TeX as described in “The \TeX Book”, the “\varepsilon-\TeX manual”, the “pdf\TeX manual”, etc. Additional reference material is published in journals of user groups and Con\TeXt related documentation.

It took about a decade to reach stable version 1.0, but for good reason. Successive versions brought new functionality, more control, some cleanup of internals and experimental features evolved into stable ones or were dropped. Already quite early Lua\TeX could be used for production and it was used on a daily basis by the authors. Successive versions sometimes demanded a adaption to the Lua interfacing, but the concepts were unchanged. The current version can be considered stable in functionality and there will be no fundamental changes. Of course we then can decide to move towards version 2.00 with different properties.

Don’t expect Lua\TeX to behave the same as pdf\TeX! Although the core functionality of that 8 bit engine was starting point, it has been combined with the directional support of Omega (Aleph). But, Lua\TeX can behave different due to its wide (32 bit) characters, many registers and large memory support. There is native utf input, support for large (more that 8 bit) fonts, and the math machinery is tuned for OpenType math. There is support for directional typesetting too. The log output can differ from other engines and will likely differ more as we move forward. When you run plain \TeX for sure Lua\TeX runs slower than pdf\TeX but when you run for instance Con\TeXt MkIV in many cases it runs faster, especially when you have a bit more complex documents or input. Anyway, 32 bit all–over combined with more features has a price, but on a modern machine this is no real problem.

Testing is done with Con\TeXt, but Lua\TeX should work fine with other macro packages too. For that purpose we provide generic font handlers that are mostly the same as used in Con\TeXt. Discussing specific implementations is beyond this manual. Even when we keep Lua\TeX lean and mean, we already have enough to discuss here.

Lua\TeX consists of a number of interrelated but (still) distinguishable parts. The organization of the source code is adapted so that it can glue all these components together. We continue cleaning up side effects of the accumulated code in \TeX engines (especially code that is not needed any longer).

- Most of pdf\TeX version 1.40.9, converted to C. Some experimental features have been removed and some utility macros are not inherited as their functionality can be done in Lua. The number of backend interface commands has been reduced to a few. The extensions are separated from the core (which we keep close to the original \TeX core). Some mechanisms like expansion and protrusion can behave different from the original due to some cleanup and optimization. Some whatsit based functionality (image support and reusable content) is now core functionality.
- The direction model and some other bits from Aleph RC4 (derived from Omega) is included. The related primitives are part of core Lua\TeX but at the node level directional support is no longer based on so called whatsits but on real nodes. In fact, whatsits are now only used for backend specific extensions.
• Neither Aleph’s I/O translation processes, nor tcx files, nor encTEX can be used, these encoding-related functions are superseded by a Lua-based solution (reader callbacks). In a similar fashion all file io can be intercepted.
• We currently use Lua 5.2.*. At some point we might decide to move to 5.3.* but that is yet to be decided. There are few Lua libraries that we consider part of the core Lua machinery, for instance lpeg. There are additional Lua libraries that interface to the internals of TeX.
• There are various TeX extensions but only those that cannot be done using the Lua interfaces. The math machinery often has two code paths: one traditional and the other more suitable for wide OpenType fonts.
• The fontloader uses parts of FontForge 2008.11.17 combined with additional code specific for usage in a TeX engine. We try to minimize specific font support to what TeX needs: character references and dimensions and delegate everything else to Lua. That way we keep TeX open for extensions without touching the core.
• The MetaPost library is integral part of LuaTeX. This gives TeX some graphical capabilities using a relative high speed graphical subsystem. Again Lua is used as glue between the frontend and backend. Further development of MetaPost is closely related to LuaTeX.

We try to keep upcoming versions compatible but intermediate releases can contain experimental features. A general rule is that versions that end up on TExlive and/or are released around ConTeXt meetings are stable. Future versions will probably become a bit leaner and meaner. Some libraries might become external as we don’t want to bloat the binary and also don’t want to add more hard coded solutions. After all, with Lua you can extend the core functionality. The less dependencies, the better.

The TeXLive version is to be considered the current stable version. Any version between the yearly TeXLive releases are to be considered beta. The beta releases are normally available via the ConTeXt distribution channels (the garden and so called minimals).

Hans Hagen, Harmut Henkel, 
Taco Hoekwater & Luigi Scarso

Version : February 15, 2017
LuaTeX : version 1, revision 3, number 1.003
ConTeXt : MkIV 2017.02.14 16:13
1 Basic \TeX{} enhancements

1.1 Introduction

From day one, \LaTeX\ has offered extra features compared to the superset of \pdf\TeX{} and Aleph. This has not been limited to the possibility to execute Lua code via \texttt{\directlua}, but \LaTeX{} also adds functionality via new \TeX{}-side primitives or extensions to existing ones.

When \LaTeX{} starts up in ‘inilatex’ mode (\texttt{\luatex -ini}), it defines only the primitive commands known by \TeX{}82 and the one extra command \texttt{\directlua}. As is fitting, a Lua function has to be called to add the extra primitives to the user environment. The simplest method to get access to all of the new primitive commands is by adding this line to the format generation file:

\begin{verbatim}
\directlua { \texpreamble{} \texClin { \extraprimitivessx } }
\end{verbatim}

But be aware that the curly braces may not have the proper \texttt{\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:

\begin{verbatim}
\catcode `{=1
\catcode `} =2
\end{verbatim}

More fine-grained primitives control is possible and you can look up the details in section 9.3.12. For simplicity’s sake, this manual assumes that you have executed the \texttt{\directlua} command as given above.

The startup behaviour documented above is considered stable in the sense that there will not be backward-incompatible changes any more. We have promoted some rather generic \pdf\TeX{} primitives to core \LaTeX{} ones, and the ones inherited from Aleph (Omega) are also promoted. Effectively this means that we now only have the \texttt{tex}, \texttt{etex} and \texttt{luatex} sets left.

In Chapter 2 we discuss several primitives that are derived from \pdf\TeX{} and Aleph (Omega). Here we stick to real new ones. In the chapters on fonts and math we discuss a few more new ones.

1.2 Version information

1.2.1 \texttt{\luatexbanner}, \texttt{\luatexversion} and \texttt{\luatexrevision}

There are three new primitives to test the version of \LaTeX{}:

<table>
<thead>
<tr>
<th>primitive</th>
<th>explanation</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{\luatexbanner}</td>
<td>the banner reported on the command line</td>
<td>This is \LaTeX{}, Version 1.0.3 (\TeX{} Live 2017/dev)</td>
</tr>
<tr>
<td>\texttt{\luatexversion}</td>
<td>a combination of major and minor number</td>
<td>100</td>
</tr>
</tbody>
</table>

Basic \TeX{} enhancements
\luatexrevision the revision number, the current value is

The official \LaTeX{} version is defined as follows:

- The major version is the integer result of \textbackslash luatexversion divided by 100. The primitive is an ‘internal variable’, so you may need to prefix its use with \textbackslash the depending on the context.
- The minor version is the two-digit result of \textbackslash luatexversion modulo 100.
- The revision is the given by \textbackslash luatexrevision. This primitive expands to a positive integer.
- The full version number consists of the major version, minor version and revision, separated by dots.

1.2.2 \formatname

The \formatname{} syntax is identical to \jobname{}. In \init\TeX{}, the expansion is empty. Otherwise, the expansion is the value that \jobname{} had during the \init\TeX{} run that dumped the currently loaded format. You can use this token list to provide your own version info.

1.3 UNICODE text support

1.3.1 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 \LaTeX{} 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, \textbackslash 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 \TeX{}-based engines. The affected commands with an altered initial (left of the equals sign) or secondary (right of the equals sign) value are: \textbackslash char, \textbackslash llc ode, \textbackslash ucc ode, \textbackslash catcode, \textbackslash sf c ode, \textbackslash ef c ode, \textbackslash lp c ode, \textbackslash rp c ode, \textbackslash 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 \texttt{reader} callback. This will be explained in a later chapter.

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 $c \geq 1,114,112$, \LaTeX{} will actually print the single byte corresponding to $c$ minus 1,114,112.

Output to the terminal uses ^^[ notation for the lower control range ($c < 32$), with the exception of ^^^I, ^^^J and ^^^M. These are considered ‘safe’ and therefore printed as-is. You can disable
escaping with `texio.setescape(false)` in which case you get the normal characters on the console.

Normalization of the Unicode input can be handled by a macro package during callback processing (this will be explained in section 8.2.14).

### 1.3.2 \Uchar

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

### 1.4 Extended tables

All traditional \TeX and \epsilon-\TeX registers can be 16-bit numbers. The affected commands are:

\begin{verbatim}
\count \countdef \box \wd
\dimen \dimendef \unhbox \ht
\skip \skipdef \unvbox \dp
\muskip \muskipdef \copy \setbox
\marks \toksdef \unhcopy \vsplit
\toks \insert \unvcopy
\end{verbatim}

Because font memory management has been rewritten, character properties in fonts are no longer shared among fonts instances that originate from the same metric file.

### 1.5 Attributes

#### 1.5.1 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.

\begin{verbatim}
\attribute {16-bit number} {optional equals} {32-bit number}
\attributedef {csname} {optional equals} {16-bit number}
\end{verbatim}

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 7.
Attributes are stored in a sorted (sparse) linked list that are shared when possible. This permits efficient testing and updating.

### 1.5.2 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 LuaTEX 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. An example:

\attribute2=5
\setbox0=\hbox {Hello}
\setbox2=\hbox attr1=12 attr2=\bbox{-"7FFFFFFF}{Hello}

This will set the attribute list of box 2 to 1 = 12, and the attributes of box 0 will be 2 = 5. As you can see, assigning the maximum negative value causes an attribute to be ignored.

The attr keyword(s) should come before a to or spread, if that is also specified.

### 1.6 LUA related primitives

#### 1.6.1 \directlua

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

\directlua (general text)
\directlua (16-bit number) (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 \TeX-style line comments (starting with %), or change the \TeX category codes locally. Another possibility is to say:

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

Then Lua line comments can be used, since \TeX does not replace line endings with spaces. Likewise, the (16-bit number) designates a name of a Lua chunk and is taken from the lua.name array (see the documentation of the lua table further in this manual). When a chunk name starts with a @ it will be displayed as a file name. This is a side effect of the way Lua implements error handling.

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

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

does not expand 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 places material on a pseudo-file to be immediately read by \TeX, as \TeX’s \texttt{\textbackslash scantokens}. For a description of print functions look at section 9.3.10.

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 still pretty bad. 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 Lua\TeX pretty bad. If you are not careful while working with the node list interface, you may even end up with assertion errors from within the \TeX portion of the executable.
The behaviour documented in the above subsection is considered stable in the sense that there will not be backward-incompatible changes any more.

### 1.6.2 \latelua

Contrary to \directlua, \latelua stores Lua code in a whatsit that will be processed at the time of shipping out. Its intended use is a cross between pdf literals (often available as \pdfliteral) and the traditional \TeX extension \write. Within the Lua code you can print pdf statements directly to the pdf file via \pdf.print, or you can write to other output streams via \textio.write or simply using Lua io routines.

\latelua \texttt{(general text)}
\latelua \texttt{(16-bit number)} \texttt{(general text)}

Expansion of macros in the final \texttt{<general text>} is delayed until just before the whatsit is executed (like in \write). With regard to pdf output stream \latelua behaves as pdf page literals. The \texttt{name} \texttt{(general text)} and \texttt{(16-bit number)} behave in the same way as they do for \directlua

### 1.6.3 \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 \texttt{n} and \texttt{r} respectively. The token sequence is fully expanded.

\luaescapestring \texttt{(general text)}

Most often, this command is not actually the best way to deal with the differences between the \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 \texttt{dofile}:

\directlua { dofile('mysetups.lua') }

### 1.6.4 \luafunction

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 use this primitive hundreds of thousands of times, it can become noticeable. 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
\luafunc2

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
}

1.7 Alignments

1.7.1 \alignmark

This primitive duplicates the functionality of # inside alignment preambles.

1.7.2 \aligntab

This primitive duplicates the functionality of & inside alignments and preambles.

1.8 Catcode tables

Catcode tables are a new feature that allows you to switch to a predefined catcode regime in a single statement. You can have a practically unlimited number of different tables. 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 tables, and their contents is stored and retrieved from the format file.

1.8.1 \catcodetable

\catcodetable \langle 15\text{-}bit number \rangle

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.

1.8.2 \initcatcodetable

\initcatcodetable \langle 15\text{-}bit number \rangle

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.

1.8.3 \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.

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.

1.9 Suppressing errors

1.9.1 \suppressfontnotfounderror

\suppressfontnotfounderror = 1

If this integer parameter is non-zero, then LuaTeX will not complain about font metrics that are not found. Instead it will silently skip the font assignment, making the requested csname for the font \ifx equal to \nullfont, so that it can be tested against that without bothering the user.

1.9.2 \suppresslongerror

\suppresslongerror = 1

If this integer parameter is non-zero, then LuaTeX will not complain about \par commands encountered in contexts where that is normally prohibited (most prominently in the arguments of non-long macros).

1.9.3 \suppressifcsnameerror

\suppressifcsnameerror = 1

If this integer parameter is non-zero, then LuaTeX will not complain about non-expandable commands appearing in the middle of a \ifcsname expansion. Instead, it will keep getting expanded
tokens from the input until it encounters an \endcsname command. If the input expansion is unbalanced with respect to \csname ...\endcsname pairs, the Lua\TeX{} process may hang indefinitely.

1.9.4 \texttt{\suppressoutererror}

\begin{Verbatim}
\suppressoutererror = 1
\end{Verbatim}

If this new integer parameter is non-zero, then Lua\TeX{} will not complain about \texttt{\outer} commands encountered in contexts where that is normally prohibited.

1.9.5 \texttt{\suppressmathparerror}

The following setting will permit \texttt{\par} tokens in a math formula:

\begin{Verbatim}
\suppressmathparerror = 1
\end{Verbatim}

So, the next code is valid then:

\begin{verbatim}
$ x + 1 = a $
\end{verbatim}

1.10 Math

1.10.1 Extensions

We will cover math 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.

1.10.2 \texttt{\matheqnogapstep}

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

\begin{Verbatim}
\matheqnogapstep = 1000
\end{Verbatim}

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 mimic floating point factors in \TeX{}.

1.11 Fonts

1.11.1 Font syntax

Lua\TeX{} 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.

### 1.11.2 \fontid

\fontid\font

This primitive expands into a number. It is not a register so there is no need to prefix with \number (and using \the gives an error). The currently used font id is 5. Here are some more:

\bf 14
\it 19
\bi 20

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 ConTeXt 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.

### 1.11.3 \setfontid

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

### 1.11.4 \noligs and \nokerns

These primitives prohibit ligature and kerning insertion at the time when the initial node list is built by Lua\TeX’\s main control loop. You can enable these primitives when you want to do node list processing of ‘characters’, where \TeX’\s normal processing would get in the way.

\noligs \langle integer \rangle
\nokerns \langle integer \rangle

These primitives can also be implemented by overloading the ligature building and kerning functions, i.e. by assigning dummy functions to their associated callbacks. Keep in mind that when you define a font (using Lua) you can also omit the kern and ligature tables, which has the same effect as the above.

### 1.11.5 \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. Below we see the results for four characters separated by a space.
1.12 Tokens, commands and strings

1.12.1 \scantextokens

The syntax of \scantextokens is identical to \scantokens. This primitive is a slightly adapted version of \TeX’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.

1.12.2 \toksapp, \tokspre, \etoksapp and \etokspre

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.

1.12.3 \csstring, \begincsname 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 that stripping it of afterwards.

The \begincsname 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.

The \lastnamedcs is one that should be used with care. The above example could be written as:
This is slightly more efficient than constructing the string twice (deep down in Lua\TeX{} this also involves some utf8 juggling), but probably more relevant is that it saves a few tokens and can make code a bit more more readable.

## 1.12.4 \clearmarks

This primitive complements the $\varepsilon$-\TeX{} mark primitives and clears a mark class completely, resetting all three connected mark texts to empty. It is an immediate command.

\begin{verbatim}
\clearmarks ⟨16-bit number⟩
\end{verbatim}

## 1.12.5 \letcharcode

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

\begin{verbatim}
\def\foo{bar} \letcharcode123\foo
\end{verbatim}

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

## 1.13 Boxes, rules and leaders

### 1.13.1 \outputbox

\begin{verbatim}
\outputbox = 65535
\end{verbatim}

This new 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.

### 1.13.2 \vpack, \hpack and \tpack

These three primitives are like \texttt{\vbox}, \texttt{\hbox} and \texttt{\vtop} but don’t apply the related callbacks.

### 1.13.3 \vsplit

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

These two concepts are now core concepts and no longer whatsits. They are in fact now implemented as rules with special properties. Normal rules have subtype 0, saved boxes have subtype 1 and images have subtype 2. This has the positive side effect that whenever we need to take content with dimensions into account, when we look at rule nodes, we automatically also deal with these two types.

The syntax of the \save...resource is the same as in pdfTeX but you should consider them to be backend specific. This means that a macro package should treat them as such and check for the current output mode if applicable. Here are the equivalents:

\saveboxresource : \pdfxform
\saveimageresource : \pdfximage
\useboxresource : \pdfrefxform
\useimageresource : \pdfrefximage
{\lastsavedboxresourceindex} : {\pdflastxform}
{\lastsavedimageresourceindex} : {\pdflastximage}
{\lastsavedimageresourcepages} : {\pdflastximagepages}

LuaTeX accepts 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

The box resources are of course implemented in the backend and therefore we do support the attr and resources keys that accept a token list. New is 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.

1.13.5 \nohrule and \novrule

Because introducing a new keyword can cause incompatibilities, 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).

1.13.6 \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.
1.14 Languages

1.14.1 \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.

1.14.2 \boundary, \noboundary, \protrusionboundary and \wordboundary

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

\xboundary 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.

1.15 Control and debugging

1.15.1 Tracing

If \tracingonline is larger than 2, the node list display will also print the node number of the nodes.

1.15.2 \outputmode and \draftmode

The \outputmode variable tells Lua\TeX{} what it has to produce:

0 dvi code
1 pdf code

The value of the \draftmode counter signals the backend if it should output less. The pdf backend accepts a value of 1, while the dvi backend ignores the value.

1.16 Files

1.16.1 File syntax

Lua\TeX{} will accept a braced argument as a file name:
This allows for embedded spaces, without the need for double quotes. Macro expansion takes place inside the argument.

### 1.16.2 Writing to file

You can now open up to 127 files with `\openout`. When no file is open writes will go to the console and log. As a consequence a system command is no longer possible but one can use `os.execute` to do the same.
2 Modifications

2.1 The merged engines

2.1.1 The need for change

The first version of Lua\TeX{} only had a few extra primitives and it was largely the same as pdf\TeX{}. Then we merged substantial parts of Aleph into the code and got more primitives. When we got more stable the decision was made to clean up the rather hybrid nature of the program. This means that some primitives have been promoted to core primitives, often with a different name, and that others were removed. This made it possible to start cleaning up the code base. In chapter 1 we discussed some new primitives, here we will cover most of the adapted ones.

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

2.1.2 Changes from \TeX{} 3.1415926

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

- The current code base is written in C, not Pascal. We use cweb when possible. As a conse-quence instead of one large file plus change files, we now have multiple files organized in categories like tex, pdf, lang, font, lua, etc. There are some artefacts of the conversion to C, but in due time we will clean up the source code and make sure that the documentation is done right. Many files are in the cweb format, but others, like those interfacing to Lua, are C files. Of course we want to stay as close as possible to the original so that the documentation of the fundamentals behind \TeX{} by Don Knuth still applies.
- See chapter 4 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.
- There is no pool file, all strings are embedded during compilation.
- 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.
- Magnification (\mag) is only supported in dvi output mode. You can set this parameter and it even works with true units till you switch to pdf output mode. When you use pdf output you can best not touch the \mag variable. This fuzzy behaviour is not much different from using pdf backend related functionality while eventually dvi output is required.
After the output mode has been frozen (normally that happens when the first page is shipped out) or when pdf output is enabled, the true specification is ignored. When you preload a plain format adapted to Lua\TeX{} it can be that the \mag parameter already has been set.
2.1.3 Changes from \texttt{\varepsilon-\TeX} 2.2

Being the de facto standard extension of course we provide the \texttt{\varepsilon-\TeX} functionality, but with a few small adaptations.

- The \texttt{\varepsilon-\TeX} functionality is always present and enabled so the prepended asterisk or \texttt{-etex} switch for \texttt{init\TeX} is not needed.
- The \texttt{\TeX} extension is not present, so the primitives \texttt{\begin{TeX}tstate}, \texttt{\begin{R}}, \texttt{\begin{L}}, \texttt{\end{R}} and \texttt{\end{L}} are missing. Instead we use the Omega approach to directionality.
- Some of the tracing information that is output by \texttt{\varepsilon-\TeX}'s \texttt{\tracingassigns} and \texttt{\tracingrestore} is not there.
- Register management in Lua\TeX uses the Aleph model, so the maximum value is 65535 and the implementation uses a flat array instead of the mixed flat&sparse model from \texttt{\varepsilon-\TeX}.
- When \texttt{kpathsea} is used to find files, Lua\TeX uses the \texttt{ofm} file format to search for font metrics. In turn, this means that Lua\TeX looks at the \texttt{OFMFONTS} configuration variable (like Omega and Aleph) instead of \texttt{TFMFONTS} (like \TeX and pdf\TeX). Likewise for virtual fonts (Lua\TeX uses the variable \texttt{OVFFONTS} instead of \texttt{VFFONTS}).

2.1.4 Changes from \texttt{PDFTeX} 1.40

Because we want to produce pdf the most natural starting point was the popular pdf\TeX program. We inherit the stable features, dropped most of the experimental code and promoted some functionality to core Lua\TeX functionality which in turn triggered renaming primitives. For compatibility reasons we still refer to \texttt{\pdf...} commands but Lua\TeX has a different backend interface. Instead of these primitives there are three interfacing primitives: \texttt{\pdfextension}, \texttt{\pdfvariable} and \texttt{\pdffeedback} that take keywords and optional further arguments. This way we can extend the features when needed but don’t need to adapt the core engine. The front-end backend are decoupled as much as possible.

- The (experimental) support for snap nodes has been removed, because it is much more natural to build this functionality on top of node processing and attributes. The associated primitives that are now gone are: \texttt{\pdfsnaprefpoint}, \texttt{\pdfsnapy}, and \texttt{\pdfsnapycmp}.
- The (experimental) support for specialized spacing around nodes has also been removed. The associated primitives that are now gone are: \texttt{\pdfadjustinterwordglue}, \texttt{\pdfprependkern}, and \texttt{\pdfappendkern}, as well as the five supporting primitives \texttt{\knbscode}, \texttt{\stbscode}, \texttt{\shbscode}, \texttt{\knbcode}, and \texttt{\knaccode}.
- A number of \texttt{pdf\TeX} primitives have been removed as they can be implemented using Lua: \texttt{\pdfelapsedtime}, \texttt{\pdfescapex}, \texttt{\pdfscapename}, \texttt{\pdfescapestring}, \texttt{\pdffiledump}, \texttt{\pdffilemoddate}, \texttt{\pdffilesize}, \texttt{\pdfforcepagebox}, \texttt{\pdflastmatch}, \texttt{\pdfmatch}, \texttt{\pdfmdfivesum}, \texttt{\pdfmovechars}, \texttt{\pdfoptionalwaysusepdffilebox}, \texttt{\pdfoptionpdfinclination}, \texttt{\pdfresettimer}, \texttt{\pdfshellescape}, \texttt{\pdfstrcmp} and \texttt{\pdfunescapehex}.
- The version related primitives \texttt{\pdftexbanner}, \texttt{\pdftexversion} and \texttt{\pdftexrevision} are no longer present as there is no longer a relationship with pdf\TeX development.
- The experimental snapper mechanism has been removed and therefore also the primitives: \texttt{\pdfignoreddimen}, \texttt{\pdffirstlineheight}, \texttt{\pdfachlineheight}, \texttt{\pdfachlinedepth} and \texttt{\pdflastlinedepth}.
• The experimental primitives \primitive, \ifprimitive, \ifabsnum and \ifabsdim are promoted to core primitives. The \pdf* prefixed originals are not available.
• The png transparency fix from 1.40.6 is not applied as high-level support is pending. Because LuaTEX has a different subsystem for managing images, more diversion from its ancestor happened in the meantime.
• Two extra token lists are provides, \pdfxformresources and \pdfxformattr, as an alternative to \pdfxform keywords.
• The current version of LuaTEX no longer replaces and/or merges fonts in embedded pdf files with fonts of the enveloping pdf document. This regression may be temporary, depending on how the rewritten font backend will look like.
• The primitives \pdfpagewidth and \pdfpageheight have been removed because \pagewidth and \pageheight have that purpose.
• The primitives \pdfnormaldeviate, \pdfuniformdeviate, \pdfsetrandomseed and \pdfrandomseed have been promoted to core primitives without pdf prefix so the original commands are no longer recognized.
• The primitives \ifincsname, \expanded and \quitvmode are now core primitives.
• As the hz and protrusion mechanism are part of the core the related primitives \lpcode, \rpcode, \efcode, \leftmarginkern, \rightmarginkern are promoted to core primitives. The two commands \protrudechars and \adjustspacing replace their prefixed with \pdf originals.
• 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 more efficient (pdf) code is generated.
• 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.
• The \tagcode primitive is promoted to core primitive.
• The \letterspacefont feature is now part of the core but will not be changed (improved). We just provide it for legacy use.
• The \pdfnoligatures primitive is now \ignoreligaturesinfont.
• The \pdfcopyfont primitive is now \copyfont.
• The \pdffontexpand primitive is now \expandglyphsinfont.
• Because position tracking is also available in dvi mode the \savepos, \lastxpos and \lastypos commands now replace their pdf prefixed originals.
• The introspective primitives \pdflastximagecolordepth and \pdfximagebbox have been removed. One can use external applications to determine these properties or use the built-in img library.
• The initializers \pdfoutput has been replaced by \outputmode and \pdfdraftmode is now \draftmode.
• The pixel multiplier dimension \pdfpxdimen loses its prefix and is now called \pxdimen.
• An extra \pdfimageaddfilename option has been added that can be used to block writing the filename to the pdf file.
• The primitive \pdftracingfonts is now \tracingfonts as it doesn't relate to the backend.
• The experimental primitive \pdfinserttht is kept as \inserttht.
• The promotion of primitives to core primitives as well as the separation of font- and backend means that the initialization namespace pdftex is gone.

One change involves the so called xforms and ximages. In pdfTeX these are implemented as so
called whatsit\textsuperscript{s}. But contrary to other whatsit\textsuperscript{\textit{s}} they have dimensions that need to be taken into account when for instance calculating optimal line breaks. In Lua\TeX\ these are now promoted to normal nodes, which simplifies code that needs those dimensions.

Another reason for promotion is that these are useful concepts. Backends can provide the ability to use content that has been rendered in several places, and images are also common. For that reason we also changed the names:

\begin{verbatim}
\newcommand{\savebox}{\pdfxform}
\newcommand{\saveimageresource}{\pdfximage}
\newcommand{\usebox}{\pdfrefxform}
\newcommand{\useimageresource}{\pdfrefximage}
\newcommand{\lastsavedboxresourceindex}{\pdflastxform}
\newcommand{\lastsavedimageresourceindex}{\pdflastximage}
\newcommand{\lastsavedimageresourcepages}{\pdflastximagepages}
\end{verbatim}

There are a few \texttt{pdffeedback} features that relate to this but these are typical backend specific ones. The index that gets returned is to be considered as ‘just a number’ and although it still has the same meaning (object related) as before, you should not depend on that.

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
- whatsit\textsuperscript{s}

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:

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

\subsection*{2.1.5 Changes from ALEPH RC4}

Because we wanted proper direction\-al typesetting the Aleph mechanisms looked most attractive. These are rather close to the ones provided by Omega, so what we say next applies to both these programs.
The extended 16-bit math primitives (\omathcode etc.) have been removed.

The OCP processing has been removed completely and as a consequence, the following primitives have been removed:
\ocp, \externalocp, \ocplist, \pushocplist, \popocplist, \clearocplists, \addbeforeocplist, \addafterocplist, \removebeforeocplist, \removeafterocplist and \ocptracelevel

Lua\TeX only understands 4 of the 16 direction specifiers of Aleph: TLT (latin), TRT (arabic), RTT (cjk), LTL (mongolian). All other direction specifiers generate an error.

The input translations from Aleph are not implemented, the related primitives are not available:
\DefaultInputMode, \noDefaultInputMode, \noInputMode, \InputMode, \DefaultOutputMode, \noDefaultOutputMode, \noOutputMode, \OutputMode, \DefaultInputTranslation, \noDefaultInputTranslation, \InputTranslation, \DefaultOutputTranslation, \noDefaultOutputTranslation, \noOutputTranslation and \OutputTranslation

Several bugs have been fixed and confusing implementation details have been sorted out.

The scanner for direction specifications now allows an optional space after the direction is completely parsed.

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 backtrack, 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.

Several mechanisms that need to be right-to-left aware have been improved. For instance placement of formula numbers.

The page dimension related primitives \pagewidth and \pageheight have been promoted to core primitives. The \hoffset and \voffset primitives have been fixed.

The primitives \charwd, \charht, \chardp and \charit have been removed as we have the \TeX variants \fontchar*.

The two dimension registers \pagerightoffset and \pagebottomoffset are now core primitives.

The direction related primitives \pagedir, \bodydir, \pardir, \textdir, \mathdir and \boxdir are now core primitives.

The promotion of primitives to core primitives as well as the removed of all others means that the initialization namespace aleph is gone.

The above let’s itself summarize as: we took the 32 bit aspects and much of the directional mechanisms.

### 2.1.6 Changes from standard WEB2C

The compilation framework is web2c and we keep using that but without the Pascal to C step. This framework also provides some common features that deal with reading bytes from files and locating files in tds. This is what we do different:

- There is no mltex support.
• There is no enctex support.
• The following encoding related command line switches are silently ignored, even in non-Lua mode: -8bit, -translate-file, -mltex, -enc and -etex.
• The \openout what sits are not written to the log file.
• Some of the so-called web2c extensions are hard to set up in non-kpse mode because texmf.cnf is not read: shell-escape is off (but that is not a problem because of Lua’s os.execute), and the paranoia checks on openin and openout do not happen. However, it is easy for a Lua script to do this itself by overloading io.open.
• The ‘E’ option does not do anything useful.

2.2 The backend primitives \pdf *

In a previous section we mentioned that some pdft\TeX primitives were removed and others promoted to core Lua\TeX primitives. That is only part of the story. In order to separate the backend specific primitives in de code these commands are now replaced by only a few. In traditional \TeX we only had the dvi backend but now we have two: dvi and pdf. Additional functionality is implemented as ‘extensions’ in \TeXspeak. By separating more strictly we are able to keep the core (fontend) clean and stable. If for some reason an extra backend option is needed, it can be implemented without touching the core. The three pdf backend related primitives are

\pdfextension command [specification]
\pdfvariable name
\pdffeedback name

An extension triggers further parsing, depending on the command given. A variable is a (kind of) register and can be read and written, while a feedback is reporting something (as it comes from the backend it’s normally a sequence of tokens).

In order for Lua\TeX to be more than just \TeX you need to enable primitives. That has already be the case right from the start. If you want the traditional pdft\TeX primitives (for as far their functionality is still around) you now can do this:

\protected\def\pdfliteral \{\pdfextension literal\}
\protected\def\pdfcolorstack \{\pdfextension colorstack\}
\protected\def\pdfsetmatrix \{\pdfextension setmatrix\}
\protected\def\pdfsave \{\pdfextension save\relax\}
\protected\def\pdfrestore \{\pdfextension restore\relax\}
\protected\def\pdfobj \{\pdfextension obj \}
\protected\def\pdfrefobj \{\pdfextension refobj \}
\protected\def\pdfannot \{\pdfextension annot \}
\protected\def\pdfstartlink \{\pdfextension startlink \}
\protected\def\pdfendlink \{\pdfextension endlink\relax\}
\protected\def\pdfdest \{\pdfextension dest \}
\protected\def\pdfthread \{\pdfextension thread \}
\protected\def\pdfstartthread \{\pdfextension starthread \}
\protected\def\pdfendthread \{\pdfextension endthread\relax\}
\protected\def\pdfinfo \{pdfextension info \}
\protected\def\pdfcatalog \{pdfextension catalog \}
\protected\def\pdfnames \{pdfextension names \}
\protected\def\pdfincludechars \{pdfextension includechars \}
\protected\def\pdffontattr \{pdfextension fontattr \}
\protected\def\pdfmapfile \{pdfextension mapfile \}
\protected\def\pdfmapline \{pdfextension mapline \}
\protected\def\pdftrailer \{pdfextension trailer \}
\protected\def\pdfglyptounicode \{pdfextension glyptounicode \}

The introspective primitives can be defined as:

\def\pdftexversion \{\numexpr\pdffeedback version\relax\}
\def\pdftexrevision \{\numexpr\pdffeedback revision\relax\}
\def\pdflastlink \{\numexpr\pdffeedback lastlink\relax\}
\def\pdfretval \{\numexpr\pdffeedback retval\relax\}
\def\pdflastobj \{\numexpr\pdffeedback lastobj\relax\}
\def\pdflastannot \{\numexpr\pdffeedback lastannot\relax\}
\def\pdfxformname \{\numexpr\pdffeedback xformname\relax\}
\def\pdfcreationdate \{\numexpr\pdffeedback creationdate\relax\}
\def\pdffontname \{\numexpr\pdffeedback fontname\relax\}
\def\pdffontobjnum \{\numexpr\pdffeedback fontobjnum\relax\}
\def\pdffontsize \{\dimexpr\pdffeedback fontsize\relax\}
\def\pdfpageref \{\numexpr\pdffeedback pageref\relax\}
\def\pdfcolorstackinit \{\pdffeedback colorstackinit\}

The configuration related registers have become:

\edef\pdfcompresslevel \{\pdfvariable compresslevel\}
\edef\pdfobjcompresslevel \{\pdfvariable objcompresslevel\}
\edef\pdfdecimaldigits \{\pdfvariable decimaldigits\}
\edef\pdfgamma \{\pdfvariable gamma\}
\edef\pdfimageresolution \{\pdfvariable imageresolution\}
\edef\pdfimageapplygamma \{\pdfvariable imageapplygamma\}
\edef\pdfimagegamma \{\pdfvariable imagegamma\}
\edef\pdfimagehicolor \{\pdfvariable imagehicolor\}
\edef\pdfimageaddfilename \{\pdfvariable imageaddfilename\}
\edef\pdfpkresolution \{\pdfvariable pkresolution\}
\edef\pdfpfixeddpi \{\pdfvariable pkfixeddpi\}
\edef\pdfinclusioncopyfonts \{\pdfvariable inclusioncopyfonts\}
\edef\pdfinclusionerrorlevel \{\pdfvariable inclusionerrorlevel\}
\edef\pdfignoreunknownimages \{\pdfvariable ignoreunknownimages\}
\edef\pdfgentounicode \{\pdfvariable gentounicode\}
\edef\pdfomitcidset \{\pdfvariable omitcidset\}
\edef\pdfpagebox \{\pdfvariable pagebox\}
\edef\pdfminorversion \{\pdfvariable minorversion\}
\edef\pdfuniqueresname \{\pdfvariable uniqueresname\}
The variables are internal ones, so they are anonymous. When you ask for the meaning of a few previously defined ones:

\meaning\pdfhorigin
\meaning\pdfcompresslevel
\meaning\pdfpageattr

you will get:

macro:->[internal backend dimension]
macro:->[internal backend integer]
macro:->[internal backend tokenlist]

The \edef can also be an \def but it’s a bit more efficient to expand the lookup related register beforehand. After that you can adapt the defaults; these are:

\pdfcompresslevel 9
\pdfobjcompresslevel 1 % used: (0,9)
\pdfdecimaldigits 4 % used: (3,6)
\pdfgamma 1000
\pdfimageresolution 71
\pdfimageapplygamma 0
\pdfimagegamma 2200
\pdfimagehicolor 1
\pdfimageaddfilename 1
\pdfpkresolution 72
\pdfpkfixeddpi 0
\pdfinclusioncopyfonts 0
\pdfinclusionerrorlevel 0
\pdfignoreunknownimages 0
\pdfgentounicode 0
If you also want some backward compatibility, you can add:

\let\pdfpagewidth \pagewidth
\let\pdfpageheight \pageheight

\let\pdfadjustspacing \adjustspacing
\let\pdfprotrudechars \protrudechars
\let\pdfnoligatures \ignoreligaturesinfont
\let\pdffontexpansion \expandglyphsinfont
\let\pdfcopyfont \copyfont

\let\pdfxform \saveboxresource
\let\pdflastxform \lastsavedboxresourceindex
\let\pdfrefxform \useboxresource

\let\pdfximage \saveimageresource
\let\pdflastximage \lastsavedimageresourceindex
\let\pdflastximagepages \lastsavedimageresourcepages
\let\pdfrefximage \useimageresource

\let\pdfsavepos \savepos
\let\pdflastxpos \lastxpos
\let\pdflastypos \lastypos

\let\pdfoutput \outputmode
\let\pdfdraftmode \draftmode

\let\pdfpxdimen \pxdimen
\let\pdfinsertht \insertht

\let\pdfnormaldeviate \normaldeviate
\let\pdfuniformdeviate \uniformdeviate
\let\pdfsetrandomseed \setrandomseed
\let\pdfrandomseed \randomseed
\let\pdfprimitive \primitive
\let\ifpdfprimitive \ifprimitive

\let\ifpdfabsnum \ifabsnum
\let\ifpdfabsdim \ifabsdim

And even:
\newdimen\pdfeachlineheight
\newdimen\pdfeachlinedepth
\newdimen\pdflastlinedepth
\newdimen\pdffirstlineheight
\newdimen\pdfignoreddimen

The backend is derived from pdfTEX so the same syntax applies. However, the outline
command accepts a \texttt{objnum} followed by a number. No checking takes place so when this is used
it had better be a valid (flushed) object.

In order to be (more or less) compatible with pdfTEX we also support the option to suppress
some info:
\pdfvariable suppressoptionalinfo \numexpr
0 + 1 % PTEX.FullBanner + 2 % PTEX.FileName + 4 % PTEX.PageNumber + 8 % PTEX.InfoDict + 16 % Creator + 32 % CreationDate + 64 % ModDate + 128 % Producer + 256 % Trapped + 512 % ID \relax

In addition you can overload the trailer id, but we don’t do any checking on validity, so you have
to pass a valid array. The following is like the ones normally generated by the engine:

\pdfvariable trailerid {[
  <FA052949448907805BA83C1E78896398>  
  <FA052949448907805BA83C1E78896398>
]}

So, you even need to include the brackets!

Although we started from a merge of pdfTEX and Aleph, by now the code base as well as func-
tionality has diverted from those parents. Here we show the options that can be passed to the
extensions.

\pdfextension literal
\pdfelement dest
um integer | name \{ tokens \}
[ fitbh | fitbv | fitb | fith | fitv | fit |
  fitr <rule spec> | xyz [ zoom <integer> ]

\pdfelement annot
reserveobjnum | useobjnum <integer>
\{ tokens \}

\pdfelement save
\pdfelement restore
\pdfelement setmatrix
\{ tokens \}
[ \immediate ] \pdfelement obj
  reserveobjnum
[ \immediate ] \pdfelement obj
  [ useobjnum <integer> ]
  [ uncompressed ]
  [ stream [ attr \{ tokens \} ] ]
  [ file ]
  \{ tokens \}
\pdfelement refobj
<integer>
\pdfelement colorstack
<integer>
  set \{ tokens \} | push \{ tokens \} | pop | current
\pdfelement startlink
[ attr \{ tokens \} ]
  user \{ tokens \} | goto | thread
  [ file \{ tokens \} ]
  [ page <integer> \{ tokens \} | name \{ tokens \} | num integer ]
  [ newwindow | nonewwindow ]
\pdfelement endlink
\pdfelement startthread
num <integer> | name \{ tokens \}
\pdfelement endthread
\pdfelement thread
2.3 Directions

The directional model in \LaTeX{} is inherited from Omega/Aleph but we tried to improve it a bit. At some point we played with recovery of modes but that was disabled later on when we found that it interfered with nested directions. That itself had as side effect that the node list was no longer balanced with respect to directional nodes which in turn can give side effects when a series of dir changes happens without grouping.
The current (0.97 onward) approach is that we again make the list balanced but 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 proper 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 dir injection.

This is what happens:

\textdir TRT nur \{\textdir TLT run \textdir TRT NUR\} nur

This becomes stepwise:

\begin{verbatim}
 injected: [+TRT]nur [+TLT]run [+TRT]NUR\} nur
 balanced: [+TRT]nur [+TLT]run [-TLT][+TRT]NUR[-TRT]} nur[-TRT]
 result : run \{RUNrun \} run
\end{verbatim}

And this:

\textdir TRT nur \{nur \textdir TLT run \textdir TRT NUR\} nur

becomes:

\begin{verbatim}
 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
\end{verbatim}

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

\textdir TRT nur \{\textdir TLT run \textdir TRT NUR\} nur

This becomes:

run RUN run run

Compare this to:

\textdir TRT nur \{\textdir TLT run \textdir TRT NUR\} nur

Which renders as:

run RUNrun run run

So how do we deal with the next?

\def\ltr{\textdir TLT}\relax
\def\rtl{\textdir TRT}\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:
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 \textdir which injects the balanced node before the skip. Instead of the previous definition we can use:

\def\ltr{\linedir TLT\relax}
\def\rtl{\linedir TRT\relax}

and this time:

\begin{verbatim}
run {\rtl nur {\ltr run \rtl NUR \ltr run \rtl NUR} nur}
run {\ltr run {\rtl nur \ltr RUN \rtl nur \ltr RUN} run}
\end{verbatim}

comes out as a properly spaced:

run run RUN run RUN run run
run run run RUN run RUN run

Anything more complex that 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.

Another adaptation to the Aleph directional model is control over shapes driven by \hangindent and \parshape. This is controlled by a new parameter \shapemode:

\begin{verbatim}
\hangindent\parshape
0 normal normal
1 mirrored normal
2 normal mirrored
3 mirrored mirrored
\end{verbatim}

The value is reset to zero (like \hangindent and \parshape) after the paragraph is done with. You can use negative values to prevent this.

In figure 2.1 a few examples are given.

\section{Implementation notes}

\subsection{Memory allocation}

The single internal memory heap that traditional \TeX used for tokens and nodes is split into two separate arrays. Each of these will grow dynamically when needed.

The \texttt{texmf.cnf} settings related to main memory are no longer used (these are: main\_memory, mem\_bot, extra\_mem\_top and extra\_mem\_bot). ‘Out of main memory’ errors can still occur, but the limiting factor is now the amount of RAM in your system, not a predefined limit.
2.4.2 Sparse arrays

The implementation of the growth of two arrays (via reallocation) introduces a potential pitfall: lists and that some nodes carry more data. But not for memory related details. Another significant detail is that we have double linked node macros called and vlink of the macros have been duplicated. For instance, there are now because of the split into two arrays and the resulting differences in the data structures, some of the macros have been duplicated. For instance, there are now vlink and vinfo as well as token_link and token_info. All access to the variable memory array is now hidden behind a macro called vmem. We mention this because using the TeXbook as reference is still quite valid but not for memory related details. Another significat detail is that we have double linked node lists and that some nodes carry more data.

The implementation of the growth of two arrays (via reallocation) introduces a potential pitfall: the memory arrays should never be used as the left hand side of a statement that can modify the array in question. Details like this are of no concern to users.

The input line buffer and pool size are now also reallocated when called, and the texmf.cnf settings buf_size and pool_size are silently ignored.

Figure 2.1 The effect of shapemode.

Also, the memory (de)allocation routines for nodes are completely rewritten. The relevant code now lives in the C file texnode.c, and basically uses a dozen or so ‘avail’ lists instead of a doubly-linked model.

Because of the split into two arrays and the resulting differences in the data structures, some of the macros have been duplicated. For instance, there are now vlink and vinfo as well as token_link and token_info. All access to the variable memory array is now hidden behind a macro called vmem. We mention this because using the TeXbook as reference is still quite valid but not for memory related details. Another significat detail is that we have double linked node lists and that some nodes carry more data.

The implementation of the growth of two arrays (via reallocation) introduces a potential pitfall: the memory arrays should never be used as the left hand side of a statement that can modify the array in question. Details like this are of no concern to users.

The input line buffer and pool size are now also reallocated when called, and the texmf.cnf settings buf_size and pool_size are silently ignored.
tables are now sparse arrays that are implemented in C. They are no longer part of the TeX ‘equivalence table’ and because each had 1.1 million entries with a few memory words each, this makes a major difference in memory usage.

The \catcode, \sfcode, \lccode, \uccode and \hjcode assignments do not yet show up when using the $\varepsilon$-TeX tracing routines \tracingassigns and \tracingrestores.

A side-effect of the current implementation is that \global is now more expensive in terms of processing than non-global assignments.

The glyph ids within a font are also managed by means of a sparse array as glyph ids can go up to index $2^{21} - 1$.

### 2.4.3 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 csnames.

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.

Active characters are internally implemented as a special type of multi-letter control sequences that uses a prefix that is otherwise impossible to obtain.

### 2.4.4 Compressed format

The format is passed through zlib, allowing it to shrink to roughly half of the size it would have had in uncompressed form. This takes a bit more cpu cycles but much less disk io, so it should still be faster.

### 2.4.5 Binary file reading

All of the internal code is changed in such a way that if one of the read_xxx_file callbacks is not set, then the file is read by a C function using basically the same convention as the callback: a single read into a buffer big enough to hold the entire file contents. While this uses more memory than the previous code (that mostly used getc calls), it can be quite a bit faster (depending on your io subsystem).
3 LUA general

3.1 Initialization

3.1.1 LUATEX as a LUA interpreter

There are some situations that make LuaTEX behave like a standalone Lua interpreter:

- if a --luaonly option is given on the command line, or
- if the executable is named texlua or luatexlua, or
- if the only non-option argument (file) on the command line 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.

LuaTEX 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.

3.1.2 LUATEX as a LUA byte compiler

There are two situations that make LuaTEX behave like the Lua byte compiler:

- if a --luaonly option is given on the command line, or
- if the executable is named texluac

In this mode, LuaTEX is exactly like luac from the stand alone Lua distribution, except that it does not have the -l switch, and that it accepts (but ignores) the --luaonly switch.

3.1.3 Other commandline processing

When the LuaTEX 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. Some options are accepted but have no consequence. The following command-line options are understood:

- --credits display credits and exit
- --debug-format enable format debugging
- --draftmode switch on draft mode i.e. generate no output in pdf mode
- --[no-]file-line-error disable/enable file:line: error style messages
- --[no-]file-line-error-style aliases of --[no-]file-line-error
- --fmt=FORMAT load the format file FORMAT
- --halt-on-error stop processing at the first error
- --help display help and exit
- --ini be iniluatex, for dumping formats
--interaction=STRING set interaction mode: batchmode, nonstopmode, scrollmode or errorstopmode
--jobname=STRING set the job name to STRING
--kpathsea-debug=NUMBER set path searching debugging flags according to the bits of NUMBER
--lua=FILE load and execute a Lua initialization script
--[no-]mktex=FMT disable/enable mktexFMT generation with FMT is tex or tfm
--nosocket disable the Lua socket library
--output-comment=STRING use STRING for dvi file comment instead of date (no effect for pdf)
--output-directory=DIR use DIR as the directory to write files to
--output-format=FORMAT use FORMAT for job output; FORMAT is dvi or pdf
--progname=STRING set the program name to STRING
--recorder enable filename recorder
--safer disable easily exploitable Lua commands
--[no-]shell-escape disable/enable system calls
--shell-restricted restrict system calls to a list of commands given in texmf.cnf
--synctex=NUMBER enable synctex
--utc use utc times when applicable
--version display version and exit

Some of the traditional flags are just ignored: --etex, --translate-file, --8bit. --[no-]parse-first-line, --default-translate-file. Also, we no longer support write18 because os.execute can do the same.

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.
- 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.

The file names for output files that are generated automatically are created by attaching the proper extension (log, pdf, etc.) to the found \jobname. These files are created in the directory pointed to by --output-directory, or in the current directory, if that switch is not present.

Without the --lua option, command line processing works like it does in any other web2c-based typesetting engine, except that LuaTEX has a few extra switches.

If the --lua option is present, LuaTEX will enter an alternative mode of command line processing in comparison to the standard web2c programs.

In this mode, a small series of actions is taken in order. First, it will parse the command line as usual, but it will only interpret a small subset of the options immediately: --safer, --nosocket, --[no-]shell-escape, --enable-write18, --disable-write18, --shell-restricted, --help, --version, and --credits.
Next Lua\TeX{} searches for the requested Lua initialization script. If it cannot be found using the actual name given on the command line, a second attempt is made by prepending the value of the environment variable $\text{LUATEXDIR}$, if that variable is defined in the environment.

Then it checks the various safety switches. You can use those to disable some Lua commands that can easily be abused by a malicious document. At the moment, `--safer nil` sets the following functions:

**Library functions**

- `os.execute`  
- `os.spawn`  
- `os.setenv`  
- `os.rename`  
- `os.remove`  
- `os.tmpdir`  
- `os.tmpfile`  
- `lfs.rmtree`  
- `lfs.mkdir`  
- `lfs.chdir`  
- `lfs.lock`  
- `lfs.touch`

Furthermore, it disables loading of compiled Lua libraries and it makes `io.open()` fail on files that are opened for anything besides reading.

When Lua\TeX{} starts it sets the locale to a neutral value. If for some reason you use `os.locale`, you need to make sure you `nil` it afterwards because otherwise it can interfere with code that for instance generates dates. You can `nil` the locale with

```lua
os.setlocale(nil, nil)
```

The `--nosocket` option makes the socket library unavailable, so that Lua cannot use networking.

The switches `--[no-]shell-escape`, `--[enable|disable]-write18`, and `--shell-restricted` have the same effects as in pd\TeX{}, and additionally make `io.popen()`, `os.execute`, `os.exec`, and `os.spawn` adhere to the requested option.

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. For that reason, the tables that deal with typesetting, like `tex`, `token`, `node` and `pdf`, are off-limits during the execution of the startup file (they are `nil’d`). Special care is taken that `texio.write` and `texio.write_nl` function properly, so that you can at least report your actions to the log file when (and if) it eventually becomes opened (note that \TeX{} does not even know its \jobname yet at this point). See chapter ?? for more information about the Lua\TeX{}-specific Lua extension tables.

Everything you do in the Lua initialization script will remain visible during the rest of the run, with the exception of the \TeX{} specific libraries like `tex`, `token`, `node` and `pdf` tables. These will be initialized to their documented state after the execution of the script. You should not store anything in variables or within tables with these four global names, as they will be overwritten completely.

We recommend you use the startup file only for your own \TeX{}-independent initializations (if you need any), to parse the command line, set values in the `texconfig` table, and register the callbacks you need.

Lua\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).
Unless the texconfig table tells Lua\TeX\ not to initialize kpathsea at all (set texconfig.kpse_init to false for that), Lua\TeX\ acts on some more command line options after the initialization script is finished: in order to initialize the built-in kpathsea library properly, Lua\TeX\ needs to know the correct program name to use, and for that it needs to check \--progname, or --ini and --fmt, if --progname is missing.

### 3.2 LUA behaviour

Lua's `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`.

Loading dynamic Lua libraries will fail if there are two Lua libraries loaded at the same time (which will typically happen on \win32, because there is one Lua 5.2 inside Lua\TeX, and another will likely be linked to the dll file of the module itself).

Lua\TeX\ is able to use the kpathsea library to find `require()`d modules. For this purpose, `package.searchers[2]` is replaced by a different loader function, that decides at runtime whether to use kpathsea or the built-in core Lua function. It uses kpathsea when that is already initialized at that point in time, otherwise it reverts to using the normal `package.path` loader.

Initialization of kpathsea can happen either implicitly (when Lua\TeX\ starts up and the startup script has not set `texconfig.kpse_init` to false), or explicitly by calling the Lua function `kpse.set_program_name()`.

Lua\TeX\ is able to use dynamically loadable Lua libraries, unless \--safer was given as an option on the command line. For this purpose, `package.searchers[3]` is replaced by a different loader function, that decides at runtime whether to use kpathsea or the built-in core Lua function. It uses kpathsea when that is already initialized at that point in time, otherwise it reverts to using the normal `package.cpath` loader.

This functionality required an extension to kpathsea:

There is a new kpathsea file format: `kpse_clua_format` that searches for files with extension `.dll` and `.so`. The `texmf.cnf` setting for this variable is `CLUAINPUTS`, and by default it has this value:

```
CLUAINPUTS=.:$SELFAUTOLOC/lib/{$proname,$engine,}/lua//
```

This path is imperfect (it requires a tds subtree below the binaries directory), but the architecture has to be in the path somewhere, and the currently simplest way to do that is to search below the binaries directory only. Of course it no big deal to write an alternative loader and use that in a macro package.

One level up (a `lib` directory parallel to `bin`) would have been nicer, but that is not doable because \TeX\Live uses a `bin/<arch>` structure.

In keeping with the other \TeX\-like programs in \TeX\Live, the two Lua functions `os.execute` and `io.popen`, as well as the two new functions `os.exec` and `os.spawn` that are explained below, take the value of `shell_escape` and/or `shell_escape_commands` in account. Whenever Lua\TeX\ is run with the assumed intention to typeset a document (and by that we mean that it is called as `luatex`, as opposed to `texlua`, and that the command line option \--luaonly was not given), it
will only run the four functions above if the matching \texttt{texmf.cnf} variable(s) or their \texttt{texconfig} (see section 9.4) counterparts allow execution of the requested system command. In ‘script interpreter’ runs of \TeX, these settings have no effect, and all four functions function as normal.

The \texttt{f:read("*line")} and \texttt{f:lines()} functions from the\textit{io} library have been adjusted so that they are line-ending neutral: any of LF, CR or CR+LF are acceptable line endings.

\texttt{luafilesystem} has been extended: there are two extra boolean functions (\texttt{lfs.isdir(filename)} and \texttt{lfs.isfile(filename)}) and one extra string field in its attributes table (permissions). There is an additional function \texttt{lfs.shortname()} which takes a file name and returns its short name on \texttt{win32} platforms. On other platforms, it just returns the given argument. The file name is not tested for existence. Finally, for non-\texttt{win32} platforms only, there is the new function \texttt{lfs.readlink()} that takes an existing symbolic link as argument and returns its content. It returns an error on \texttt{win32}.

The \texttt{string} library has an extra function: \texttt{string.explode(s[,m])}. This function returns an array containing the string argument \texttt{s} split into sub-strings based on the value of the string argument \texttt{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 \texttt{m} is ‘+’ (multiple spaces). Note: \texttt{m} is not hidden by surrounding braces as it would be if this function was written in \TeX macros.

The \texttt{string} library also has six extra iterators that return strings piecemeal:

- \texttt{string.utfvalues(s)}: an integer value in the Unicode range
- \texttt{string.utfcharacters(s)}: a string with a single utf-8 token in it
- \texttt{string.characters(s)} a string containing one byte
- \texttt{string.characterpairs(s)} two strings each containing one byte or an empty second string if the string length was odd
- \texttt{string.bytes(s)} a single byte value
- \texttt{string.bytepairs(s)} two byte values or \texttt{nil} instead of a number as its second return value if the string length was odd

The \texttt{string.characterpairs()} and \texttt{string.bytepairs()} iterators are useful especially in the conversion of utf16 encoded data into utf8.

There is also a two-argument form of \texttt{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.

The \texttt{string} library functions \texttt{len}, \texttt{lower}, \texttt{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 \texttt{slnunicode} library can be used, e.g., \texttt{unicode.utf8.len}, \texttt{unicode.utf8.lower} etc. The exceptions are \texttt{unicode.utf8.find}, that always returns byte positions in a string, and \texttt{unicode.utf8.match} and \texttt{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 \texttt{unicode.utf8} functions refer to the library sources at http://luaforge.net/projects/sln. Version 5.3 of Lua will provide some native utf8 support.

The \texttt{os} library has a few extra functions and variables:
• **os.selfdir** is a variable that holds the directory path of the actual executable. For example:

```
\directlua{tex.sprint(os.selfdir)}
```

• **os.exec(commandline)** is a variation on **os.execute**. Here **commandline** can be either a single string or a single table.

If the argument is a table **LuaTeX** first checks if there is a value at integer index zero. If there is, this is the command to be executed. Otherwise, it will use the value at integer index one. If neither are present, nothing at all happens.

The set of consecutive values starting at integer 1 in the table are the arguments that are passed on to the command (the value at index 1 becomes **arg[0]**). The command is searched for in the execution path, so there is normally no need to pass on a fully qualified path name. If the argument is a string, then it is automatically converted into a table by splitting on whitespace. In this case, it is impossible for the command and first argument to differ from each other.

In the string argument format, whitespace can be protected by putting (part of) an argument inside single or double quotes. One layer of quotes is interpreted by **LuaTeX**, and all occurrences of \", \, or \ \ within the quoted text are unescaped. In the table format, there is no string handling taking place.

This function normally does not return control back to the Lua script: the command will replace the current process. However, it will return the two values **nil** and **error** if there was a problem while attempting to execute the command.

On MS Windows, the current process is actually kept in memory until after the execution of the command has finished. This prevents crashes in situations where **TeX** **Lua** scripts are run inside integrated **TeX** environments.

The original reason for this command is that it cleans out the current process before starting the new one, making it especially useful for use in **TeX** **Lua**.

• **os.spawn(commandline)** is a returning version of **os.exec**, with otherwise identical calling conventions.

If the command ran ok, then the return value is the exit status of the command. Otherwise, it will return the two values **nil** and **error**.

• **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. This function is not available on the SunOS platforms, so do not use this function for portable documents.

• **os.times()** returns the current process times according to the Unix C library function ‘times’. This function is not available on the MS Windows and SunOS platforms, so do not use this function for portable documents.

• **os.tmpdir()** creates a directory in the ‘current directory’ with the name **luatex.XXXXXX** where the X-es are replaced by a unique string. The function also returns this string, so you can **lfs.chdir()** into it, or **nil** if it failed to create the directory. The user is responsible for cleaning up at the end of the run, it does not happen automatically.

• **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 pos-
sible values are not yet fixed, and for \texttt{os.type} values \texttt{windows} and \texttt{msdos}, the \texttt{os.name} values are simply \texttt{windows} and \texttt{msdos}.

The list for the type \texttt{unix} is more precise: \texttt{linux}, \texttt{freebsd}, \texttt{kfreebsd}, \texttt{cygwin}, \texttt{openbsd}, \texttt{solaris}, \texttt{sunos} (pre-\texttt{solaris}), \texttt{hpux}, \texttt{irix}, \texttt{macosx}, \texttt{gnu (hurd)}, \texttt{bsd} (unknown, but \texttt{bsd-like}), \texttt{sysv} (unknown, but \texttt{sysv-like}), \texttt{generic} (unknown).

- \texttt{os.uname()} returns a table with specific operating system information acquired at runtime. The keys in the returned table are all string valued, and their names are: \texttt{sysname}, \texttt{machine}, \texttt{release}, \texttt{version}, and \texttt{nodename}.

In stock Lua, many things depend on the current locale. In \LaTeX, we can’t do that, because it makes documents unportable. While \LaTeX is running if forces the following locale settings:

\begin{verbatim}
LC_CTYPE=C
LC_COLLATE=C
LC_NUMERIC=C
\end{verbatim}

### 3.3 LUA modules

Some modules that are normally external to Lua are statically linked in with \LaTeX, because they offer useful functionality:

- \texttt{slnunicode}, from the selene libraries, http://luaforge.net/projects/sln. This library has been slightly extended so that the \texttt{unicode.utf8.*} functions also accept the first 256 values of plane 18. This is the range \LaTeX uses for raw binary output, as explained above.
- \texttt{luazip}, from the kepler project, http://www.keplerproject.org/luazip/.
- \texttt{luafilesystem}, also from the kepler project, http://www.keplerproject.org/luafilesystem/.
- \texttt{lpeg}, by Roberto Ierusalimschy, http://www.inf.puc-rio.br/~roberto/lpeg/lpeg.html. This library is not Unicode-aware, but interprets strings on a byte-per-byte basis. This mainly means that \texttt{lpeg.S} cannot be used with utf8 characters encoded in more than two bytes, and thus \texttt{lpeg.S} will look for one of those two bytes when matching, not the combination of the two. The same is true for \texttt{lpeg.R}, although the latter will display an error message if used with multibyte characters. Therefore \texttt{lpeg.R('aâ')} results in the message \texttt{bad argument #1 to 'R' (range must have two characters)}, since to \texttt{lpeg}, â is two `characters' (bytes), so â totals three. In practice this is no real issue.
- \texttt{luasocket}, by Diego Nehab http://w3.impa.br/~diego/software/luasocket/. The .lua support modules from \texttt{luasocket} are also preloaded inside the executable, there are no external file dependencies.

At some point (this also depends on distributions) \LaTeX might have these libraries loaded on demand. For this reason you can best use \texttt{require} to make sure they are loaded.

### 3.4 Testing

For development reasons you can influence the used startup date and time. This can be done in two ways.
1. By setting the environment variable \texttt{SOURCE\_DATE\_EPOCH}. This will influence the \TeX\ parameters \texttt{time} and \texttt{date}, the random seed, the pdf timestamp and the pdf id that is derived from the time as well. This variable is consulted when the \texttt{kpsen} library is enabled. Resolving is delegated to this library.

2. By setting the \texttt{start\_time} variable in the \texttt{texconfig} table; as with other variables we use the internal name there. For compatibility reasons we also honour a \texttt{SOURCE\_DATE\_EPOCH} entry. It should be noted that there are no such variables in other engines and this method is only relevant in case the while setup happens in Lua.

When Universal Time is needed, you can pass the flag \texttt{utc} to the engine. This property also works when the date and time are set by Lua\TeX\ itself. It has a complementary entry \texttt{use\_utc\_time} in the \texttt{texconfig} table.

\textit{To some extend a cleaner solution would be to have a flag that disables all variable data in one go (like filenames and so) but we just follow the method implemented in pdf\TeX\ where primitives are used to influence other properties.}

\textit{In Con\TeX\ we provide the command line argument \texttt{- -nodates} that does bit more disabling of dates.}
4 Languages, characters, fonts and glyphs

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 records 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.

4.1 Characters and glyphs

\TeX82 (including pdf\TeX) 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 LuaTeX, these two types are merged into one, somewhat larger structure called a glyph_node. Besides having the old character, font, and component fields, and the new special fields like ‘attr’ (see section 7.1.2.12), these nodes also contain:
• A subtype, split into four main types:
  – 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 ligatures (bit 1 is set)
  – ghost, for ‘ghost objects’ (bit 2 is set)

The latter two make further use of two extra fields (bits 3 and 4):
  – left, for ligatures created from a left word boundary and for ghosts created from \left-ghost
  – right, for ligatures created from a right word boundary and for ghosts created from \rightghost

For ligatures, both bits can be set at the same time (in case of a single-glyph word).

• glyph_node of type ‘character’ 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 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 \savinghyphcodes to a value larger 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:

\hjcode`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 \savinghyphcodes was zero when the language got initialized you start out with nothing, otherwise you already have a set.

When a \hjcode is larger than 0 but smaller 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 œ counts as one character. Because traditionally zero itself is reserved for inhibiting hyphenation, a value of 32 counts as zero.
% assuming french patterns:
 foo-bar % foo-bar

\hjcode`x=`o

fxxbar % fxx-bar

\lefthyphenmin3

œdipus % œdi-pus

\lefthyphenmin4

œdipus % œdipus

\hjcode`œ=2

œdipus % œdi-pus

\hjcode`i=32

\hjcode`d=32

œdipus % œdipus

Carrying all this information with each glyph would give too much overhead and also make the process of setting up the codes more complex. A solution with hj code 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 \savinghyph-codes 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 trigger. Here are a few examples of usage:

discrete---discrete
discrete_
discrete
discrete\discretionary{}{}{}---discrete
discrete
discrete
discrete\wordboundary\discretionary{}{}{}---discrete
dis-
dcrete
discrete
We only accept an explicit hyphen when there is a preceding glyph and we skip a sequence of explicit hyphens as 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 the separating the hyphenation, ligaturing and kerning steps.

The start and end of a characters is signalled by a glue, penalty, kern or boundary node. But by default also a hlist, vlist, rule, dir, whatsit, ins, and adjust node indicate a start or end. You can omit the last set from the test by setting \hyphenationbounds to a non-zero value:

0 not strict
1 strict start
2 strict end
3 strict start and strict end

The word start is determined as follows:

boundary yes when wordboundary
hlist when hyphenationbounds 1 or 3
vlist when hyphenationbounds 1 or 3
rule when hyphenationbounds 1 or 3
dir when hyphenationbounds 1 or 3
whatsit when hyphenationbounds 1 or 3
 glue yes
math skipped
glyph exhyphenchar (one only) : yes (so no --)
otherwise yes

The word end is determined as follows:

boundary yes
glyph yes when different language
 glue yes
penalty yes
kern yes when not italic (for some historic reason)
hlist when hyphenationbounds 2 or 3
vlist when hyphenation bounds 2 or 3
rule when hyphenation bounds 2 or 3
dir when hyphenation bounds 2 or 3
whatsit when hyphenation bounds 2 or 3
ins when hyphenation bounds 2 or 3
adjust when hyphenation bounds 2 or 3

(Future versions of LuaTeX might provide more granularity.)

4.2 The main control loop

In LuaTeX'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.

First, the \accent primitives 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 TeX82 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.\footnote{Of course, modern packages will not use the \accent primitive at all but try to map directly on composed characters.} A secondary reason is that in TeX82, \accent prohibits hyphenation of the current word. Since in LuaTeX hyphenation only takes place on 'character' nodes, it is possible to achieve the same effect.

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 LuaTeX 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.

Second, all the results of processing in math mode eventually become nodes with 'glyph' subtypes.

Third, the Aleph-derived commands \leftghost and \rightghost create nodes of a third subtype: 'ghost'. These nodes are ignored completely by all further processing until the stage where inter-glyph kerning is added.

Fourth, automatic discretionary lines are handled differently. TeX82 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.\footnote{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.}

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. Initex sets the \exhyphenchar=`\-. 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 Lua\TeX\ has for \texttt{\hyphenchar} is at the check whether a word should be considered for hyphenation at all. If the \texttt{\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 \texttt{\hyphenchar=-1} as a means of preventing hyphenation should not be used in new Lua\TeX\ documents.

Fifth, \texttt{\setlanguage} no longer creates what'sits. The meaning of \texttt{\setlanguage} is changed so that it is now an integer parameter like all others. That integer parameter is used in \texttt{\glyph_node} creation to add language information to the glyph nodes. In conjunction, the \texttt{\language} primitive is extended so that it always also updates the value of \texttt{\setlanguage}.

Sixth, the \texttt{\noboundary} 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 \texttt{\noboundary} command in the input stream has to be retained until after the ligature and font processing stages.

Finally, there is no longer a \texttt{main\_loop} label in the code. Remember that \TeX\82 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 Lua\TeX\, 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 \texttt{\tracingcommands} is on, this is visible because the full word is reported, instead of just the initial character.

### 4.3 Loading patterns and exceptions

The hyphenation algorithm in Lua\TeX\ is quite different from the one in \TeX\82, although it uses essentially the same user input.

After expansion, the argument for \texttt{\patterns} has to be proper utf8 with individual patterns separated by spaces, no \texttt{\char} or \texttt{\chardef} commands are allowed. The current implementation quite strict and will reject all non-Unicode characters.

Likewise, the expanded argument for \texttt{\hyphenation} also has to be proper utf8, but here a bit of extra syntax is provided:

1. Three sets of arguments in curly braces ({{}{}}) indicates a desired complex discretionary, with arguments as in \texttt{\discretionary}'s command in normal document input.
2. A - indicates a desired simple discretionary, cf. \texttt{-} and \texttt{\discretionary{-}{{}{}{}}} in normal document input.
3. Internal command names are ignored. This rule is provided especially for \texttt{\discretionary}, but it also helps to deal with \texttt{\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:
<table>
<thead>
<tr>
<th>value</th>
<th>implied key (input)</th>
<th>effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>ta-ble</td>
<td>table</td>
<td>ta-ble (= ta\discretionary{-}{}){}{}ble</td>
</tr>
<tr>
<td>ba{\k-}{{}c}ken</td>
<td>backen</td>
<td>ba\discretionary{k-}{{}c}ken</td>
</tr>
</tbody>
</table>

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 Lua\TeX using one of the functions in the Lua \lang 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 $\varepsilon$-\TeX extension \savinghyphcodes was that hyphenation heavily depended on font encodings. This is no longer true in Lua\TeX, and the corresponding primitive is basically ignored. Because we now have hjcode, the case relate codes can be used exclusively for \uppercase and \lowercase.

### 4.4 Applying hyphenation

The internal structures Lua\TeX uses for the insertion of discretionaries in words is very different from the ones in \TeX82, 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 patgen-generated pattern files, but Lua\TeX uses a finite state hash to match the patterns against the word to be hyphenated. This algorithm is based on the ‘libhnj’ library used by OpenOffice, which in turn is inspired by \TeX.

There are a few differences between Lua\TeX and \TeX82 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 \lang.patterns) can be used at any time, not only in init\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.
• **LuaTeX** uses the language-specific variables \prehyphenchar and \posthyphenchar in the creation of implicit discretionaries, instead of T\!E\!X\!\!82’s \hyphenchar, and the values of the language-specific variables \preexhyphenchar and \postexhyphenchar for explicit discretionaries (instead of T\!E\!X\!\!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 T\!E\!X. When you apply the Lua \lang.hyphenate function the current values are used.

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:

\hsize1mm
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.

LuaT\!E\!X also hyphenates the first word in a paragraph. Words can be up to 256 characters long (up from 64 in T\!E\!X\!\!82). Longer words generate an error 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 T\!E\!X\!\!82, but there the behaviour cannot be controlled).

If you are using the Lua function \lang.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.

The hyphenation exception dictionary is maintained as key-value hash, and that is also dynamic, so the hyph\_size setting is not used either.
4.5 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 work 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.

Work in this area is not yet complete, but most of the possible cases are handled by our rewritten ligaturing engine. At some point all of the possible inputs will become supported.³

For example, take the word *office*, hyphenated *of-fice*, using a ‘normal’ font with all the *f*-f and *f*-i type ligatures:

Initial: \{o\}{f\}{i\}{c\}{e}\n
After hyphenation: \{o\}{f\}{\{\-.\}}{i\}{c\}{e}\n
First ligature stage: \{o\}{\{\-.\}}{f\}{\{<ff>\}}{i\}{c\}{e}\n
Final result: \{o\}{\{\-.\}}{\{<fi>\}}{<ffi>}{c\}{e}\n
That’s bad enough, but let us assume that there is also a hyphenation point between the *f* and the *i*, to create *of-f-ice*. Then the final result should be:

\{o\}{\{\-.\}}\n
\{\{\-.\}\}\n
\{i\}\n
\{<fi>\}\n
\{\{<ff>-\}\}\n
\{i\}\n
\{<ffi>\}\n
\{c\}{e}\n
with discretionaries in the post-break text as well as in the replacement text of the top-level discretionary that resulted from the first hyphenation point.

Here is that nested solution again, in a different representation:

<table>
<thead>
<tr>
<th>pre</th>
<th>post</th>
<th>replace</th>
</tr>
</thead>
<tbody>
<tr>
<td>topdisc</td>
<td>f·1</td>
<td>sub1</td>
</tr>
<tr>
<td>sub1</td>
<td>&lt;ff&gt;-·5</td>
<td>i⁶</td>
</tr>
</tbody>
</table>

³ Not all of this makes sense because we nowadays have OpenType fonts and ligature building can happen in any different ways there.
When line breaking is choosing its breakpoints, the following fields will eventually be selected:

<table>
<thead>
<tr>
<th>of-f-ice</th>
<th>f-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f-2</td>
</tr>
<tr>
<td></td>
<td>i3</td>
</tr>
<tr>
<td>of-f-ice</td>
<td>f-1</td>
</tr>
<tr>
<td></td>
<td>&lt;fi&gt;4</td>
</tr>
<tr>
<td>off-ice</td>
<td>&lt;ff&gt;-5</td>
</tr>
<tr>
<td></td>
<td>i6</td>
</tr>
<tr>
<td>office</td>
<td>&lt;ffi&gt;7</td>
</tr>
</tbody>
</table>

The current solution in LuaTeX is not able to handle nested discretionaries, but it is in fact smart enough to handle this fictional of-f-ice example. It does so by combining two sequential discretionary nodes as if they were a single object (where the second discretionary node is treated as an extension of the first node).

One can observe that the of-f-ice and off-ice cases both end with the same actual post replacement list (i), and that this would be the case even if that i was the first item of a potential following ligature like ic. This allows LuaTeX to do away with one of the fields, and thus make the whole stuff fit into just two discretionary nodes.

The mapping of the seven list fields to the six fields in this discretionary node pair is as follows:

<table>
<thead>
<tr>
<th>field description</th>
</tr>
</thead>
<tbody>
<tr>
<td>disc1.pre</td>
</tr>
<tr>
<td>disc1.post</td>
</tr>
<tr>
<td>disc1.replace</td>
</tr>
<tr>
<td>disc2.pre</td>
</tr>
<tr>
<td>disc2.post</td>
</tr>
<tr>
<td>disc2.replace</td>
</tr>
</tbody>
</table>

What is actually generated after ligaturing has been applied is therefore:

```
{o}\{f-},
{<fi>},
{<ffi>}}
{{f-},
{[i],
{<ff>-}}{{c}{e}}
```

The two discretionaries have different subtypes from a discretionary appearing on its own: the first has subtype 4, and the second has subtype 5. The need for these special subtypes stems from the fact that not all of the fields appear in their 'normal' location. The second discretionary especially looks odd, with things like the <ff>- appearing in disc2.replace. The fact that some of the fields have different meanings (and different processing code internally) is what makes it necessary to have different subtypes: this enables LuaTeX to distinguish this sequence of two joined discretionary nodes from the case of two standalone discretionaries appearing in a row.

Of course there is still that relationship with fonts: ligatures can be implemented by mapping a sequence of glyphs onto one glyph, but also by selective replacement and kerning. This means that the above examples are just representing the traditional approach.
4.6 Breaking paragraphs into lines

This code is still almost unchanged, but because of the above-mentioned changes with respect to discretionaries and ligatures, line breaking will potentially be different from traditional \TeX. The actual line breaking code is still based on the \TeX82 algorithms, and it does not expect there to be discretionaries inside of discretionaries.

But that situation is now fairly common in Lua\TeX, due to the changes to the ligaturing mechanism. And also, the Lua\TeX discretionary nodes are implemented slightly different from the \TeX82 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 \TeX the discretionary node contains a counter indicating how many nodes to skip, but in Lua\TeX we store the pre, post and replace text in the discretionary node.

The combined effect of these two differences is that Lua\TeX 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.

4.7 The \texttt{lang} library

This library provides the interface to Lua\TeX’s structure representing a language, and the associated functions.

\begin{verbatim}
<language> l = lang.new()
<language> l = lang.new(<number> id)
\end{verbatim}

This function creates a new userdata object. An object of type \texttt{<language>} is the first argument to most of the other functions in the \texttt{lang} 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.

\begin{verbatim}
<number> n = lang.id(<language> l)
\end{verbatim}

returns the internal \texttt{\backslash language id} number this object refers to.

\begin{verbatim}
<string> n = lang.hyphenation(<language> l)
lang.hyphenation(<language> l, <string> n)
\end{verbatim}

Either returns the current hyphenation exceptions for this language, or adds new ones. The syntax of the string is explained in section 4.3.

\begin{verbatim}
lang.clear_hyphenation(<language> l)
\end{verbatim}

Clears the exception dictionary (string) for this language.

\begin{verbatim}
<string> n = lang.clean(<language> l, <string> o)
<string> n = lang.clean(<string> o)
\end{verbatim}
Creates a hyphenation key from the supplied hyphenation value. The syntax of the argument string is explained in section 4.3. This function is useful if you want to do something else based on the words in a dictionary file, like spell-checking.

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

Adds additional patterns for this language object, or returns the current set. The syntax of this string is explained in section 4.3.

lang.clear_patterns(<language> l)

Clears the pattern dictionary for this language.

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

Gets or sets the ‘pre-break’ hyphen character for implicit hyphenation in this language (initially the hyphen, decimal 45).

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

Gets or sets the ‘post-break’ hyphen character for implicit hyphenation in this language (initially null, decimal 0, indicating emptiness).

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

Gets or sets the ‘pre-break’ hyphen character for explicit hyphenation in this language (initially null, decimal 0, indicating emptiness).

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

Gets or sets the ‘post-break’ hyphen character for explicit hyphenation in this language (initially null, decimal 0, indicating emptiness).

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

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.

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 4.1 for more details.

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

lang.sethjcode(<language> l, <number> char, <number> usedchar)
<number> usedchar = lang.getjcode(<language> l, <number> char)

When you set a hjcode the current sets get initialized unless the set was already initialized due to \savinghycodes being larger than zero.
## 5 Font structure

### 5.1 The font tables

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 returned by the define_font callback, or if they result from the normal tfm/vf reading routines if there is no define_font callback defined.

The column ‘vf’ means that this key will be created by the font.read_vf() routine, ‘tfm’ means that the key will be created by the font.read_tfm() routine, and ‘used’ means whether or not the LuaTeX engine itself will do something with the key.

The top-level keys in the table are as follows:

<table>
<thead>
<tr>
<th>key</th>
<th>vf</th>
<th>tfm</th>
<th>used</th>
<th>value</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>string</td>
<td>metric (file) name</td>
<td></td>
</tr>
<tr>
<td>area</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>string</td>
<td>(directory) location, typically empty</td>
<td></td>
</tr>
<tr>
<td>used</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>boolean</td>
<td>indicates usage (initial: false)</td>
<td></td>
</tr>
<tr>
<td>characters</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>table</td>
<td>the defined glyphs of this font</td>
<td></td>
</tr>
<tr>
<td>checksum</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>default: 0</td>
<td></td>
</tr>
<tr>
<td>designsize</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>expected size (default: 655360 == 10pt)</td>
<td></td>
</tr>
<tr>
<td>direction</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>default: 0</td>
<td></td>
</tr>
<tr>
<td>encodingbytes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>default: depends on format</td>
<td></td>
</tr>
<tr>
<td>encodingname</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>encoding name</td>
<td></td>
</tr>
<tr>
<td>fonts</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>table</td>
<td>locally used fonts</td>
<td></td>
</tr>
<tr>
<td>psname</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>This is the PostScript fontname in the incoming font source, and it’s used as font-name identifier in the pdf output. This has to be a valid string, e.g. no spaces and such, as the backend will not do a cleanup. This gives complete control to the loader.</td>
<td></td>
</tr>
<tr>
<td>fullname</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>output font name, used as a fallback in the pdf output if the psname is not set</td>
<td></td>
</tr>
<tr>
<td>header</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>string</td>
<td>header comments, if any</td>
<td></td>
</tr>
<tr>
<td>hyphenchar</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>default: TeX’s \hyphenchar</td>
<td></td>
</tr>
<tr>
<td>parameters</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>hash</td>
<td>default: 7 parameters, all zero</td>
<td></td>
</tr>
<tr>
<td>size</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>loaded (at) size. (default: same as design-size)</td>
<td></td>
</tr>
<tr>
<td>skewchar</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>default: TeX’s \skewchar</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>basic type of this font</td>
<td></td>
</tr>
<tr>
<td>format</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>disk format type</td>
<td></td>
</tr>
<tr>
<td>embedding</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>pdf inclusion</td>
<td></td>
</tr>
<tr>
<td>filename</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>the name of the font on disk</td>
<td></td>
</tr>
<tr>
<td>tounicode</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>When this is set to 1 LuaTeX assumes per-glyph tounicode entries are present in the font.</td>
<td></td>
</tr>
<tr>
<td>Key</td>
<td>Required</td>
<td>Optional</td>
<td>Required</td>
<td>Value Type</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>----------</td>
<td>----------</td>
<td>----------</td>
<td>------------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>stretch</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>the ‘stretch’ value from <code>\expandglyphsinfont</code></td>
<td></td>
</tr>
<tr>
<td>shrink</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>the ‘shrink’ value from <code>\expandglyphsinfont</code></td>
<td></td>
</tr>
<tr>
<td>step</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>the ‘step’ value from <code>\expandglyphsinfont</code></td>
<td></td>
</tr>
<tr>
<td>auto_expand</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>boolean</td>
<td>the ‘autoexpand’ keyword from <code>\expandglyphsinfont</code></td>
<td></td>
</tr>
<tr>
<td>expansion_factor</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>number</td>
<td>the actual expansion factor of an expanded font</td>
<td></td>
</tr>
<tr>
<td>attributes</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>the <code>\pdffontattr</code></td>
<td></td>
</tr>
<tr>
<td>cache</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>string</td>
<td>This key controls caching of the Lua table on the TeX end where yes means: use a reference to the table that is passed to LuaTeX (this is the default), and no no means: don’t store the table reference, don’t cache any Lua data for this font while renew means: don’t store the table reference, but save a reference to the table that is created at the first access to one of its fields in font. Note: the saved reference is thread-local, so be careful when you are using coroutines: an error will be thrown if the table has been cached in one thread, but you reference it from another thread.</td>
<td></td>
</tr>
<tr>
<td>nomath</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>boolean</td>
<td>This key allows a minor speedup for text fonts. If it is present and true, then LuaTeX will not check the character entries for math-specific keys.</td>
<td></td>
</tr>
<tr>
<td>oldmath</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>boolean</td>
<td>This key flags a font as representing an old school TeX math font and disables the OpenType code path.</td>
<td></td>
</tr>
<tr>
<td>slant</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>This has the same semantics as the SlantFont operator in font map files.</td>
<td></td>
</tr>
<tr>
<td>extent</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>This has the same semantics as the ExtendFont operator in font map files.</td>
<td></td>
</tr>
</tbody>
</table>

The key name is always required. The keys stretch, shrink, step and optionally auto_expand only have meaning when used together: they can be used to replace a post-loading `\expandglyphsinfont` command. The expansion_factor is value that can be present inside a font in `font.fonts`. It is the actual expansion factor (a value between -shrink and stretch, with step step) of a font that was automatically generated by the font expansion algorithm. The key attributes can be used to set font attributes in the pdf file. The key used is set by the engine when a font is actively in use, this makes sure that the font’s definition is written to the output file (dvi or pdf). The tfm reader sets it to false. The direction is a number signalling the ‘normal’ direction for this font. There are sixteen possibilities:
These are Omega-style direction abbreviations: the first character indicates the ‘first’ edge of the character glyphs (the edge that is seen first in the writing direction), the second the ‘top’ side. Keep in mind that LuaTeX has a bit different directional model so these values are not used for anything.

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:

<table>
<thead>
<tr>
<th>name</th>
<th>remapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>slant</td>
<td>1</td>
</tr>
<tr>
<td>space</td>
<td>2</td>
</tr>
<tr>
<td>space_stretch</td>
<td>3</td>
</tr>
<tr>
<td>space_shrink</td>
<td>4</td>
</tr>
<tr>
<td>x_height</td>
<td>5</td>
</tr>
<tr>
<td>quad</td>
<td>6</td>
</tr>
<tr>
<td>extra_space</td>
<td>7</td>
</tr>
</tbody>
</table>

The keys type, format, embedding, fullname and filename are used to embed OpenType fonts in the result pdf.

The characters table is a list of character hashes indexed by an integer number. The number is the ‘internal code’ TeX knows this character by.

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).

Other index keys are ignored.

Each character hash itself is a hash. For example, here is the character ‘f’ (decimal 102) in the font cmr10 at 10pt:

```javascript
[102] = {
    ['width'] = 200250,
    ['height'] = 455111,
    ['depth'] = 0,
    ['italic'] = 50973,
    ['kerns'] = {
```
The following top-level keys can be present inside a character hash:

<table>
<thead>
<tr>
<th>key</th>
<th>vf</th>
<th>tfm</th>
<th>used</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>character’s width, in sp (default 0)</td>
</tr>
<tr>
<td>height</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>character’s height, in sp (default 0)</td>
</tr>
<tr>
<td>depth</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>character’s depth, in sp (default 0)</td>
</tr>
<tr>
<td>italic</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>character’s italic correction, in sp (default zero)</td>
</tr>
<tr>
<td>top_accent</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>number</td>
<td>character’s top accent alignment place, in sp</td>
</tr>
<tr>
<td>bot_accent</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>number</td>
<td>character’s bottom accent alignment place, in sp</td>
</tr>
<tr>
<td>left_protruding</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>number</td>
<td>character’s \textcode{l}pcode</td>
</tr>
<tr>
<td>right_protruding</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>number</td>
<td>character’s \textcode{r}PCODE</td>
</tr>
<tr>
<td>expansion_factor</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>number</td>
<td>character’s \textcode{e}FCode</td>
</tr>
<tr>
<td>tounicode</td>
<td>no</td>
<td>no</td>
<td>maybe</td>
<td>string</td>
<td>character’s Unicode equivalent(s), in utf-16BE</td>
</tr>
<tr>
<td>next</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>number</td>
<td>the ‘next larger’ character index</td>
</tr>
<tr>
<td>extensible</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>table</td>
<td>the constituent parts of an extensible recipe</td>
</tr>
<tr>
<td>vert_variants</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>table</td>
<td>constituent parts of a vertical variant set</td>
</tr>
<tr>
<td>horiz_variants</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>table</td>
<td>constituent parts of a horizontal variant set</td>
</tr>
<tr>
<td>kerns</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>table</td>
<td>kerning information</td>
</tr>
<tr>
<td>ligatures</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
<td>table</td>
<td>ligaturing information</td>
</tr>
<tr>
<td>commands</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
<td>array</td>
<td>virtual font commands</td>
</tr>
<tr>
<td>name</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>string</td>
<td>the character (PostScript) name</td>
</tr>
<tr>
<td>index</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>number</td>
<td>the (OpenType or TrueType) font glyph index</td>
</tr>
</tbody>
</table>
used no yes yes boolean typeset already (default: false)?
mathkern no no yes table math cut-in specifications

The values of top_accent, bot_accent and mathkern are used only for math accent and superscript placement, see the math chapter 79 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.

The usage of tounicode is this: if this font specifies a tounicode=1 at the top level, then LuaTeX will construct a /ToUnicode entry for the pdf font (or font subset) based on the character-level tounicode strings, where they are available. If a character does not have a sensible Unicode equivalent, do not provide a string either (no empty strings).

If the font level tounicode is not set, then LuaTeX will build up /ToUnicode based on the TeX code points you used, and any character-level tounicodes will be ignored. The string format is exactly the format that is expected by Adobe CMap files (utf-16BE in hexadecimal encoding), minus the enclosing angle brackets. For instance the tounicode for a fi ligature would be 00660069. When you pass a number the conversion will be done for you.

The presence of extensible will overrule next, if that is also present. It in in turn can be overruled by vert_variants.

The extensible table is very simple:

```
<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>top</td>
<td>number</td>
<td>top character index</td>
</tr>
<tr>
<td>mid</td>
<td>number</td>
<td>middle character index</td>
</tr>
<tr>
<td>bot</td>
<td>number</td>
<td>bottom character index</td>
</tr>
<tr>
<td>rep</td>
<td>number</td>
<td>repeatable character index</td>
</tr>
</tbody>
</table>
```

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

```
<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>glyph</td>
<td>number</td>
<td>The character index. Note that this is an encoding number, not a name.</td>
</tr>
<tr>
<td>extender</td>
<td>number</td>
<td>One (1) if this part is repeatable, zero (0) otherwise.</td>
</tr>
<tr>
<td>start</td>
<td>number</td>
<td>The maximum overlap at the starting side (in scaled points).</td>
</tr>
<tr>
<td>end</td>
<td>number</td>
<td>The maximum overlap at the ending side (in scaled points).</td>
</tr>
<tr>
<td>advance</td>
<td>number</td>
<td>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.</td>
</tr>
</tbody>
</table>
```

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 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:
The character 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 TeX. When TeX 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’.

<table>
<thead>
<tr>
<th>textual (Knuth)</th>
<th>number</th>
<th>string</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>l + r :=: n</td>
<td>0</td>
<td>:=</td>
<td></td>
</tr>
<tr>
<td>l + r :=:</td>
<td>n</td>
<td>1</td>
<td>:=</td>
</tr>
<tr>
<td>l + r</td>
<td>=: n</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>l + r</td>
<td>=:</td>
<td>n</td>
<td>3</td>
</tr>
<tr>
<td>l + r ::= n</td>
<td>5</td>
<td>::=</td>
<td>n</td>
</tr>
<tr>
<td>l + r ::=</td>
<td>n</td>
<td>6</td>
<td>::=</td>
</tr>
<tr>
<td>l + r ::=</td>
<td>&gt; n</td>
<td>7</td>
<td>::=&gt;</td>
</tr>
<tr>
<td>l + r ::=</td>
<td>&gt;&gt; n</td>
<td>11</td>
<td>::=</td>
</tr>
</tbody>
</table>

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.

The commands array is explained below.

5.2 Real fonts

Whether or not a TeX font is a ‘real’ font that should be written to the pdf document is decided by the type value in the top-level font structure. If the value is real, then this is a proper font, and the inclusion mechanism will attempt to add the needed font object definitions to the pdf.

Values for type are:

<table>
<thead>
<tr>
<th>value</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>real</td>
<td>this is a base font</td>
</tr>
<tr>
<td>virtual</td>
<td>this is a virtual font</td>
</tr>
</tbody>
</table>

The actions to be taken depend on a number of different variables:

- Whether the used font fits in an 8-bit encoding scheme or not.
- The type of the disk font file.
- The level of embedding requested.

A font that uses anything other than an 8-bit encoding vector has to be written to the pdf in a different way.

The rule is: if the font table has encodingbytes set to 2, then this is a wide font, in all other cases it isn’t. The value 2 is the default for OpenType and TrueType fonts loaded via Lua. For Type1
fonts, you have to set encodingbytes to 2 explicitly. For=pk bitmap fonts, wide font encoding is
not supported at all.

If no special care is needed, \LaTeX{} currently falls back to the mapfile-based solution used by
PDF\LaTeX{} and dvips. This behaviour might silently be removed in the future, in which case the
related primitives and Lua functions will become no-ops.

If a ‘wide’ font is used, the new subsystem kicks in, and some extra fields have to be present in
the font structure. In this case, \LaTeX{} does not use a map file at all.

The extra fields are: format, embedding, fullname, cidinfo (as explained above), filename,
and the index key in the separate characters.

Values for format are:

<table>
<thead>
<tr>
<th>value</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>type1</td>
<td>this is a PostScript Type1 font</td>
</tr>
<tr>
<td>type3</td>
<td>this is a bitmapped (pk) font</td>
</tr>
<tr>
<td>truefont</td>
<td>this is a TrueType or TrueType-based OpenType font</td>
</tr>
<tr>
<td>opentype</td>
<td>this is a PostScript-based OpenType font</td>
</tr>
</tbody>
</table>

\texttt{type3} fonts are provided for backward compatibility only, and do not support the new wide
encoding options.

Values for embedding are:

<table>
<thead>
<tr>
<th>value</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>no</td>
<td>don’t embed the font at all</td>
</tr>
<tr>
<td>subset</td>
<td>include and attempt to subset the font</td>
</tr>
<tr>
<td>full</td>
<td>include this font in its entirety</td>
</tr>
</tbody>
</table>

The other fields are used as follows: The fullname will be the PostScript/pdf font name. The
cidinfo will be used as the character set (the CID /Ordering and /Registry keys). The filename points to the actual font file. If you include the full path in the filename or if the file is in the local directory, \LaTeX{} will run a little bit more efficient because it will not have to re-run
the \texttt{find\_xxx\_file} callback in that case.

Be careful: when mixing old and new fonts in one document, it is possible to create PostScript
name clashes that can result in printing errors. When this happens, you have to change the
fullname of the font.

Typeset strings are written out in a wide format using 2 bytes per glyph, using the index key
in the character information as value. The overall effect is like having an encoding based on
numbers instead of traditional (PostScript) name-based reencoding. The way to get the correct
index numbers for Type1 fonts is by loading the font via \texttt{fontloader.open} and use the table
indices as index fields.

In order to make sure that cut and paste of the final document works okay you can best make
sure that there is a tounicode vector enforced.
5.3 Virtual fonts

5.3.1 The structure

You have to take the following steps if you want LuaTeX to treat the returned table from `define_font` as a virtual font:

- Set the top-level key `type` to `virtual`.
- Make sure there is at least one valid entry in `fonts` (see below).
- Give a `commands` array to every character (see below).

The presence of the top-level key `type` with the specific value `virtual` will trigger handling of the rest of the special virtual font fields in the table, but the mere existence of 'type' is enough to prevent LuaTeX from looking for a virtual font on its own.

Therefore, this also works 'in reverse': if you are absolutely certain that a font is not a virtual font, assigning the value `base` or `real` to `type` will inhibit LuaTeX from looking for a virtual font file, thereby saving you a disk search.

The `fonts` is another Lua array. 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, you can use the `font.nextid()` function which returns the index of the next to be defined font which is probably the currently defined one.

An example makes this easy to understand

```lua
fonts = {
    { name = 'ptmr8a', size = 655360 },
    { name = 'psyr', size = 600000 },
    { id = 38 }
}
```

says that the first referenced font (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 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 allowed commands and their arguments are:

<table>
<thead>
<tr>
<th>command name</th>
<th>arguments</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>font</td>
<td>1</td>
<td>number</td>
<td>select a new font from the local fonts table</td>
</tr>
<tr>
<td>char</td>
<td>1</td>
<td>number</td>
<td>typeset this character number from the current font, and move right by the character's width</td>
</tr>
<tr>
<td>node</td>
<td>1</td>
<td>node</td>
<td>output this node (list), and move right by the width of this list</td>
</tr>
<tr>
<td>slot</td>
<td>2</td>
<td>number</td>
<td>a shortcut for the combination of a font and char command</td>
</tr>
</tbody>
</table>
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 (normally one could use font.nextid but when more complex fonts are built in the meantime other instances could have been loaded. Here is a rather elaborate glyph commands example:

```lua
... 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')
    { 'pop' }, -- go all the way back
    { 'down', -200000 }, -- move upwards by about 3pt
    { 'special', 'pdf: 1 0 0 rg' } -- switch to red color
    { 'rule', 500000, 20000 } -- draw a bar
    { 'special','pdf: 0 g' } -- back to black
}
...```

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 create 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.

### 5.3.2 Artificial fonts

Even in a ‘real’ font, there can be virtual characters. When LuaTEX encounters a commands field inside a character when it becomes time to typeset the character, it will interpret the commands, just like for a true virtual character. In this case, if you have created no ‘fonts’ array, then the default (and only) ‘base’ font is taken to be the current font itself. In practice, this means that
you can create virtual duplicates of existing characters which is useful if you want to create composite characters.

Note: this feature does not work the other way around. There cannot be ‘real’ characters in a virtual font! You cannot use this technique for font re-encoding either; you need a truly virtual font for that (because characters that are already present cannot be altered).

### 5.3.3 Example virtual font

Finally, here is a plain \TeX{} input file with a virtual font demonstration:

\begin{verbatim}
\directlua {
    callback.register('define_font',
        function (name,size)
            if name == 'cmr10-red' then
                f = font.read_tfm('cmr10',size)
                f.name = 'cmr10-red'
                f.type = 'virtual'
                f.fonts = {{ name = 'cmr10', size = size }}
                for i,v in pairs(f.characters) do
                    if (string.char(i)):find('^[tacohanshartmut]$') then
                        v.commands = {
                            {'special','pdf: 1 0 0 rg'},
                            {'char',i},
                            {'special','pdf: 0 g'},
                        }
                    else
                        v.commands = {{'char',i}}
                    end
                end
            else
                f = font.read_tfm(name,size)
            end
            return f
        end
    )
\end{verbatim}

\font \myfont = cmr10-red at 10pt \myfont This is a line of text \par
\font \myfontx = cmr10 at 10pt \myfontx Here is another line of text \par

### 5.4 The font library

The font library provides the interface into the internals of the font system, and also it contains helper functions to load traditional \TeX{} font metrics formats. Other font loading functionality is provided by the fontloader library that will be discussed in the next section.
5.4.1 Loading a TFM file

The behavior documented in this subsection is considered stable in the sense that there will not be backward-incompatible changes any more.

```lua
define fnt =
  font.read_tfm(<string> name, <number> s)
```

The number 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 designsize of the font.

The internal structure of the metrics font table that is returned is explained in chapter 5.

5.4.2 Loading a VF file

The behavior documented in this subsection is considered stable in the sense that there will not be backward-incompatible changes any more.

```lua
define vf_fnt =
  font.read_vf(<string> name, <number> s)
```

The meaning of the number \(s\) and the format of the returned table are similar to the ones in the `read_tfm()` function.

5.4.3 The fonts array

The whole table of \(\TeX\) fonts is accessible from Lua using a virtual array.

```lua
font.fonts[n] = { ... }
```

```lua
<table> f = font.fonts[n]
```

See chapter 5 for the structure of the tables. Because this is a virtual array, you cannot call `pairs` on it, but see below for the `font.each` iterator.

The two metatable functions implementing the virtual array are:

```lua
<table> f = font.getfont(<number> n)
```

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

Note that at the moment, each access to the `font.fonts` or call to `font.getfont` creates a Lua table for the whole font. This process can be quite slow. In a later version of Lua\TeX, this interface will change (it will start using userdata objects instead of actual tables).

Also note the following: assignments can only be made to fonts that have already been defined in \(\TeX\), but have not been accessed at all since that definition. This limits the usability of the write access to `font.fonts` quite a lot, a less stringent ruleset will likely be implemented later.
5.4.4 Checking a font’s status

You can test for the status of a font by calling this function:

```plaintext
<boolean> f =
    font.frozen(<number> n)
```

The return value is one of true (unassignable), false (can be changed) or nil (not a valid font at all).

5.4.5 Defining a font directly

You can define your own font into font.fonts by calling this function:

```plaintext
<number> i =
    font.define(<table> f)
```

The return value is the internal id number of the defined font (the index into font.fonts). If the font creation fails, an error is raised. The table is a font structure, as explained in chapter 5.

5.4.6 Projected next font id

```plaintext
<number> i =
    font.nextid()
```

This returns the font id number that would be returned by a font.define call if it was executed at this spot in the code flow. This is useful for virtual fonts that need to reference themselves.

5.4.7 Font id

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

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

5.4.8 Currently active font

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

This gets or sets the currently used font number.

5.4.9 Maximum font id

```plaintext
<number> i =
    font.max()
```
This is the largest used index in \texttt{font.fonts}.

\section{5.4.10 Iterating over all fonts}

\begin{verbatim}
for i,v in font.each() do
  ...
end
\end{verbatim}

This is an iterator over each of the defined \TeX fonts. The first returned value is the index in \texttt{font.fonts}, the second the font itself, as a Lua table. The indices are listed incrementally, but they do not always form an array of consecutive numbers: in some cases there can be holes in the sequence.
6 Math

The handling of mathematics in LuaTeX differs quite a bit from how \TeX\ (and therefore pdf\TeX) handles math. First, LuaTeX adds primitives and extends some others so that Unicode input can be used easily. Second, all of \TeX\’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.

6.1 The current math style

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: \texttt{\textstyle}. This is a ‘convert command’ like e.g. \texttt{\romannumeral}: its value can only be read, not set.

6.1.1 \texttt{\textstyle}

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 the can be used as numeric values, so you can write code like this:

\texttt{\\quad\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 \texttt{\fam 12} mid-formula spoils over to preceding use of that family).

The style switching primitives like \texttt{\textstyle} are turned into nodes so the styles set there are frozen. The \texttt{\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 \texttt{\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.

\texttt{[a:\mathstyle]\quad}
This gives:

\begin{align*}
[a:0] & \quad (x:d:4) \quad [b:0] \quad (y:d:4) \quad [c:0] \quad (z:ss:6) \quad [d:0] \\
[a:2] & \quad (x:t:6) \quad [b:2] \quad (y:t:6) \quad [c:2] \quad (z:ss:6) \quad [d:2]
\end{align*}

Using \begingroup ... \endgroup instead gives:

\begin{align*}
[a:0] & \quad (x:d:4) \quad [b:0] \quad (y:ss:6) \quad [c:0] \quad (z:ss:6) \quad [d:0] \\
[a:2] & \quad (x:t:6) \quad [b:2] \quad (y:ss:6) \quad [c:2] \quad (z:ss:6) \quad [d:2]
\end{align*}

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.

\section{\texttt{\textbackslash Ustack}}

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

\begin{verbatim}
$\Ustack \{a \over b\}$
\end{verbatim}

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

### 6.2 Unicode math characters

Character handling is now extended up to the full Unicode range (the \texttt{\textbackslash U} prefix), which is compatible with \TeX\textsuperscript{82}.

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

Some of the new Lua\TeX primitives read more than one separate value. This is shown in the tables below by a plus sign in the second column.

The input for such primitives would look like this:

\begin{verbatim}
def\overbrace{\texttt{\textbackslash Umathaccent 0 1 "23DE }}
\end{verbatim}

The altered \TeX\textsuperscript{82} primitives are:

<table>
<thead>
<tr>
<th>primitive</th>
<th>min</th>
<th>max</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{\textbackslash mathcode}</td>
<td>0</td>
<td>10FFFF</td>
<td>0</td>
<td>8000</td>
</tr>
<tr>
<td>\texttt{\textbackslash delcode}</td>
<td>0</td>
<td>10FFFF</td>
<td>0</td>
<td>FFFFFF</td>
</tr>
</tbody>
</table>

The unaltered ones are:

<table>
<thead>
<tr>
<th>primitive</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{\textbackslash mathchardef}</td>
<td>0</td>
<td>8000</td>
</tr>
<tr>
<td>\texttt{\textbackslash mathchar}</td>
<td>0</td>
<td>7FFF</td>
</tr>
<tr>
<td>\texttt{\textbackslash mathaccent}</td>
<td>0</td>
<td>7FFF</td>
</tr>
<tr>
<td>\texttt{\textbackslash delimiter}</td>
<td>0</td>
<td>7FFFFFF</td>
</tr>
<tr>
<td>\texttt{\textbackslash radical}</td>
<td>0</td>
<td>7FFFFFF</td>
</tr>
</tbody>
</table>

For practical reasons \texttt{\textbackslash mathchardef} will silently accept values larger that 0x8000 and interpret it as \texttt{\textbackslash Umathcharnumdef}. This is needed to satisfy older macro packages.

The following new primitives are compatible with \TeX\textsuperscript{82}:

<table>
<thead>
<tr>
<th>primitive</th>
<th>min</th>
<th>max</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{\textbackslash Umathchardef}</td>
<td>0+0+0</td>
<td>7FF+10FFFF\textsuperscript{1}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash Umathcharnumdef\textsuperscript{5}}</td>
<td>-80000000</td>
<td>7FFFFFFFFFFF\textsuperscript{3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash mathcode}</td>
<td>0</td>
<td>10FFFF</td>
<td>0+0+0</td>
<td>7FF+10FFFF\textsuperscript{1}</td>
</tr>
<tr>
<td>\texttt{\textbackslash Udelcode}</td>
<td>0</td>
<td>10FFFF</td>
<td>0+0</td>
<td>FF+10FFFF\textsuperscript{2}</td>
</tr>
<tr>
<td>\texttt{\textbackslash mathchar}</td>
<td>0+0+0</td>
<td>7FF+10FFFF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash mathaccent}</td>
<td>0+0+0</td>
<td>7FF+10FFFF\textsuperscript{2,4}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash delimiter}</td>
<td>0+0+0</td>
<td>7FF+10FFFF\textsuperscript{2}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash radical}</td>
<td>0+0</td>
<td>FF+10FFFF\textsuperscript{2}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash Umathcharnum}</td>
<td>-80000000</td>
<td>7FFFFFFFFFFF\textsuperscript{3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>\texttt{\textbackslash Umathcodenum}</td>
<td>0</td>
<td>10FFFF</td>
<td>-80000000</td>
<td>7FFFFFFFFFFF\textsuperscript{3}</td>
</tr>
<tr>
<td>\texttt{\textbackslash Udelcodenum}</td>
<td>0</td>
<td>10FFFF</td>
<td>-80000000</td>
<td>7FFFFFFFFFFF\textsuperscript{3}</td>
</tr>
</tbody>
</table>
Specifications typically look like:

\mathchardef xx="1"0"456
\mathcode 123="1"0"789

Note 1: 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 \mathoperatorsize parameter (more information can be found in a following section).

Note 2: For these three primitives, all information is packed into a single signed integer. For the first two (\mathcharnum and \mathcodenum), 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 \delcodenum 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.

Note 3: The \mathaccent command accepts optional keywords to control various details regarding math accents. See section 6.9 below for details.

New primitives that exist in Lua\TeX{} only (all of these will be explained in following sections):

<table>
<thead>
<tr>
<th>primitive</th>
<th>value range (in hex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Uroot</td>
<td>0+0-FF+10FFFFF²</td>
</tr>
<tr>
<td>\Uoverdelimiter</td>
<td>0+0-FF+10FFFFF²</td>
</tr>
<tr>
<td>\Uunderdelimiter</td>
<td>0+0-FF+10FFFFF²</td>
</tr>
<tr>
<td>\Udelimiterover</td>
<td>0+0-FF+10FFFFF²</td>
</tr>
<tr>
<td>\Udelimiterunder</td>
<td>0+0-FF+10FFFFF²</td>
</tr>
</tbody>
</table>

### 6.3 Cramped math styles

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 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. If we force styles in the script using \scriptstyle and \crampedscriptstyle we get this:

\begin{align*}
\text{default} & \quad b^x = x \\
\text{script} & \quad b^x = x \\
\text{crampedscript} & \quad b^x = x
\end{align*}

Now we set the following parameters

\begin{align*}
\Umathordrelspacing\scriptstyle &= 30 \text{mu} \\
\Umathordordspacing\scriptstyle &= 30 \text{mu}
\end{align*}

This gives:

\begin{align*}
\text{default} & \quad b^x = x \\
\text{script} & \quad b^x = x \\
\text{crampedscript} & \quad b^x = x
\end{align*}

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

\begin{align*}
\Umathordrelspacing\scriptstyle &= 30 \text{mu} \\
\Umathordordspacing\scriptstyle &= 30 \text{mu} \\
\Umathordrelspacing\crampedscriptstyle &= 30 \text{mu} \\
\Umathordordspacing\crampedscriptstyle &= 30 \text{mu}
\end{align*}

Now we get:

\begin{align*}
\text{default} & \quad b^x = x \\
\text{script} & \quad b^x = x \\
\text{crampedscript} & \quad b^x = x
\end{align*}

\section*{6.4 Math parameter settings}

In Lua\TeX, 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 many more parameters than were accessible before.

\begin{tabular}{ll}
\textbf{primitive name} & \textbf{description} \\
\Umathquad & the width of 18 \text{mu}'s \\
\Umathaxis & height of the vertical center axis of the math formula above the baseline \\
\Umathoperatorsize & minimum size of large operators in display mode \\
\Umathoverbarkern & vertical clearance above the rule \\
\Umathoverbarrule & the width of the rule
\end{tabular}
\texttt{\textbackslash Umathunderbarvgap} \quad \text{vertical clearance below the rule}
\texttt{\textbackslash Umathunderbarkern} \quad \text{vertical clearance below the rule}
\texttt{\textbackslash Umathunderbarrule} \quad \text{the width of the rule}
\texttt{\textbackslash Umathunderbarvgap} \quad \text{vertical clearance above the rule}
\texttt{\textbackslash Umathradicalkern} \quad \text{vertical clearance above the rule}
\texttt{\textbackslash Umathradicalrule} \quad \text{the width of the rule}
\texttt{\textbackslash Umathradicalvgap} \quad \text{vertical clearance below the rule}
\texttt{\textbackslash Umathradicaldegreebefore} \quad \text{the forward kern that takes place before placement of the radical degree}
\texttt{\textbackslash Umathradicaldegreeafter} \quad \text{the backward kern that takes place after placement of the radical degree}
\texttt{\textbackslash Umathradicaldegreeraise} \quad \text{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}
\texttt{\textbackslash Umathstackvgap} \quad \text{vertical clearance between the two elements in a \texttt{\atop} stack}
\texttt{\textbackslash Umathstacknumup} \quad \text{numerator shift upward in \texttt{\atop} stack}
\texttt{\textbackslash Umathstackdenomdown} \quad \text{denominator shift downward in \texttt{\atop} stack}
\texttt{\textbackslash Umathfractionrule} \quad \text{the width of the rule in a \texttt{\over} fraction}
\texttt{\textbackslash Umathfractionnumvgap} \quad \text{vertical clearance between the numerator and the rule}
\texttt{\textbackslash Umathfractionnumup} \quad \text{numerator shift upward in \texttt{\over} fraction}
\texttt{\textbackslash Umathfractiondenomdown} \quad \text{denominator shift downward in \texttt{\over} fraction}
\texttt{\textbackslash Umathfractiondenomvgap} \quad \text{vertical clearance between the denominator and the rule}
\texttt{\textbackslash Umathfractiondelimits} \quad \text{minimum delimiter size for \texttt{\ldots withdelims}}
\texttt{\textbackslash Umathlimitabovevgap} \quad \text{vertical clearance for limits above operators}
\texttt{\textbackslash Umathlimitabovebgap} \quad \text{vertical baseline clearance for limits above operators}
\texttt{\textbackslash Umathlimitabovekern} \quad \text{space reserved at the top of the limit}
\texttt{\textbackslash Umathlimitbelowvgap} \quad \text{vertical clearance for limits below operators}
\texttt{\textbackslash Umathlimitbelowbgap} \quad \text{vertical baseline clearance for limits below operators}
\texttt{\textbackslash Umathlimitbelowkern} \quad \text{space reserved at the bottom of the limit}
\texttt{\textbackslash Umathoverflowdelimitervgap} \quad \text{vertical clearance for limits above delimiters}
\texttt{\textbackslash Umathoverflowdelimiterbgap} \quad \text{vertical baseline clearance for limits above delimiters}
\texttt{\textbackslash Umathunderdelimitervgap} \quad \text{vertical clearance for limits below delimiters}
\texttt{\textbackslash Umathunderdelimiterbgap} \quad \text{vertical baseline clearance for limits below delimiters}
\texttt{\textbackslash Umathsubshiftdrop} \quad \text{subscript drop for boxes and subformulas}
\texttt{\textbackslash Umathsubshiftdown} \quad \text{subscript drop for characters}
\texttt{\textbackslash Umathsupshiftdrop} \quad \text{superscript drop (raise, actually) for boxes and subformulas}
\texttt{\textbackslash Umathsupshiftup} \quad \text{superscript raise for characters}
\texttt{\textbackslash Umathsubsupshiftdown} \quad \text{subscript drop in the presence of a superscript}
\texttt{\textbackslash Umathsubtopmax} \quad \text{the top of standalone subscripts cannot be higher than this above the baseline}
\texttt{\textbackslash Umathsupbottommin} \quad \text{the bottom of standalone superscripts cannot be less than this above the baseline}
\texttt{\textbackslash Umathsupsubbottommax} \quad \text{the bottom of the superscript of a combined super- and subscript be at least as high as this above the baseline}
\texttt{\textbackslash Umathsubsupvgap} \quad \text{vertical clearance between super- and subscript}
Each of the parameters in this section can be set by a command like this:

\mathquad\displaystyle=1em

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

6.5 Skips around display math

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 later makes it sometimes hard to fully control spacing. Therefore Lua\TeX\ comes with a new directive: \mathdisplayskipmode. The following values apply:

0 normal \TeX\ behaviour: always above, only below when larger than zero
1 always
2 only when not zero
3 never, not even when not zero

6.6 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, Lua\TeX\ 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 \msy \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 using in the \TeX\book. 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, Lua\TeX\ also looks at the ‘space’ font dimension parameter. For math fonts, this should be set to zero.

<table>
<thead>
<tr>
<th>variable</th>
<th>style</th>
<th>default value opentype</th>
<th>default value tfm</th>
</tr>
</thead>
<tbody>
<tr>
<td>\mathaxis</td>
<td>-</td>
<td>AxisHeight</td>
<td>axis_height</td>
</tr>
<tr>
<td>\mathoperatorsize</td>
<td>D, D’</td>
<td>DisplayOperatorMinHeight</td>
<td>6</td>
</tr>
<tr>
<td>\mathfractiondelsize</td>
<td>D, D’</td>
<td>FractionDelimiterDisplayStyleSize</td>
<td>delim1</td>
</tr>
<tr>
<td>\mathfractiondelsize</td>
<td>T, T’, S, S’, SS, SS’</td>
<td>FractionDelimiterDisplayStyleSize</td>
<td>delim2</td>
</tr>
<tr>
<td>\mathfractiondenomdown</td>
<td>D, D’</td>
<td>FractionDenominatorDisplayStyleShiftDown</td>
<td>denom1</td>
</tr>
<tr>
<td>\mathfractiondenomdown</td>
<td>T, T’, S, S’, SS, SS’</td>
<td>FractionDenominatorDisplayStyleShiftDown</td>
<td>denom2</td>
</tr>
</tbody>
</table>
\mathfractiondenomvgap \quad \text{FractionDenominatorDisplayStyleGapMin}\quad 3*\text{default_rule_thickness}

\mathfractionnumup \quad \text{FractionNumeratorDisplayStyleShiftUp}\quad \text{num1}

\mathfractionnumvgap \quad \text{FractionNumeratorDisplayStyleGapMin}\quad \text{num2}

\mathfractionrule \quad \text{FractionRuleThickness}\quad \text{default_rule_thickness}

\mathskewedfractionhgap \quad \text{SkewedFractionHorizontalGap}\quad \text{math_quad/2}

\mathskewedfractionvgap \quad \text{SkewedFractionVerticalGap}\quad \text{math_x_height}

\mathlimitabovebgap \quad \text{UpperLimitBaselineRiseMin}\quad \text{big_op_spacing3}

\mathlimitabovekern \quad \text{0}\quad \text{big_op_spacing5}

\mathlimitabovevgap \quad \text{UpperLimitGapMin}\quad \text{big_op_spacing1}

\mathlimitbelowbgap \quad \text{LowerLimitBaselineDropMin}\quad \text{big_op_spacing4}

\mathlimitbelowkern \quad \text{0}\quad \text{big_op_spacing5}

\mathlimitbelowvgap \quad \text{LowerLimitGapMin}\quad \text{big_op_spacing2}

\mathoverdelimitervgap \quad \text{StretchStackGapBelowMin}\quad \text{big_op_spacing1}

\mathoverdelimiterbgap \quad \text{StretchStackTopShiftUp}\quad \text{big_op_spacing3}

\mathunderdelimitervgap \quad \text{StretchStackGapAboveMin}\quad \text{big_op_spacing2}

\mathunderdelimiterbgap \quad \text{StretchStackBottomShiftDown}\quad \text{big_op_spacing4}

\mathoverbarkern \quad \text{OverbarExtraAscender}\quad \text{default_rule_thickness}

\mathoverbarrule \quad \text{OverbarRuleThickness}\quad \text{default_rule_thickness}

\mathoverbarvgap \quad \text{OverbarVerticalGap}\quad 3*\text{default_rule_thickness}

\mathradicalkern \quad \text{RadicalExtraAscender}\quad \text{default_rule_thickness}

\mathradicalrule \quad \text{RadicalRuleThickness}\quad \text{<not set>^2}

\mathradicalgap \quad \text{RadicalDisplayStyleVerticalGap}\quad \text{(default_rule_thickness+}

\mathradicaldegreebefore \quad \text{RadicalKernBeforeDegree}\quad \text{(abs(math_x_height)/4))^3}

\mathradicaldegreeafter \quad \text{RadicalKernAfterDegree}\quad \text{(abs(default_rule_thickness)/4))^3}

\mathradicaldegreeraise \quad \text{RadicalDegreeBottomRaisePercent}\quad \text{(not set)^2,7}

\mathspaceafterscript \quad \text{SpaceAfterScript}\quad \text{script_space^4}

\mathstackdenomdown \quad \text{StackBottomDisplayStyleShiftDown}\quad \text{denom1}

\mathstacknumup \quad \text{StackTopDisplayStyleShiftUp}\quad \text{num1}

\mathstackvgap \quad \text{StackDisplayStyleGapMin}\quad \text{num3}

\mathsubshiftdown \quad \text{SubscriptShiftDown}\quad \text{sub1}

\mathsubshiftdrop \quad \text{SubscriptBaselineDropMin}\quad \text{sub_drop}

\mathsubsupshiftdown \quad \text{or SubscriptShiftDownWithSuperscript}\quad \text{sub2}

\mathsubtopmax \quad \text{SubscriptTopMax}\quad \text{(abs(math_x_height*4)/5)}

\mathsubsupvgap \quad \text{SubSuperscriptGapMin}\quad \text{4*default_rule_thickness}

\mathsupbottommin \quad \text{SuperscriptBottomMin}\quad \text{(abs(math_x_height)/4)}

\mathsupbottommin \quad \text{SuperscriptBaselineDropMax}\quad \text{sup_drop}

\mathsupshiftup \quad \text{SuperscriptShiftUp}\quad \text{sup1}

\mathquad \quad \text{<font_size(f)>^1}

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Note 1: OpenType fonts set \texttt{Umathlimitabovekern} and \texttt{Umathlimitbelowkern} to zero and set \texttt{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 \texttt{Umathradicalrule} because \TeX{}82 uses the height of the radical instead. When this parameter is indeed not set when Lua\TeX{} 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 \texttt{Umathradicaldegreebefore}, \texttt{Umathradicaldegreeafter}, and \texttt{Umathradicaldegreeraise}. These are then automatically initialized to \(\frac{5}{18}\) quad, \(-\frac{10}{18}\) quad, and 60.

Note 3: If tfm fonts are used, then the \texttt{Umathradicalvgap} is not set until the first time Lua\TeX{} has to typeset a formula because this needs parameters from both family 2 and family 3. This provides a partial backward compatibility with \TeX{}82, but that compatibility is only partial: once the \texttt{Umathradicalvgap} is set, it will not be recalculated any more.

Note 4: When tfm fonts are used a similar situation arises with respect to \texttt{Umathspaceafterscript}: it is not set until the first time Lua\TeX{} has to typeset a formula. This provides some backward compatibility with \TeX{}82. But once the \texttt{Umathspaceafterscript} is set, \texttt{scriptspace} will never be looked at again.

Note 5: Traditional tfm fonts set \texttt{Umathconnectoroverlapmin} to zero because \TeX{}82 always stacks extensibles without any overlap.

Note 6: The \texttt{Umathoperatorsize} is only used in \texttt{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 \TeX{}82.

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

Note 8: \texttt{SubscriptShiftDownWithSuperscript} does not actually exist in the ‘standard’ OpenType math font Cambria, but it is useful enough to be added.

Note 9: \texttt{FractionDelimiterDisplayStyleSize} and \texttt{FractionDelimiterSize} do not actually exist in the ‘standard’ OpenType math font Cambria, but were useful enough to be added.

### 6.7 Nolimit correction

There are two extra math parameters \texttt{Umathnolimitsupfactor} and \texttt{Umathnolimitsubfactor} 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 \texttt{Umathnolimitmode}. The half corrections are what happens when scripts are placed on 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, does the kerns assume correction too. Anyway, with this parameter one can control it.

\[
\int_1^0 \int_1^0 \int_1^0 \int_1^0 \int_1^0 \int_1^0
\]

<table>
<thead>
<tr>
<th>mode</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>superscript</td>
<td>0</td>
<td>font</td>
<td>0</td>
<td>0</td>
<td>+ic/2</td>
<td>0</td>
</tr>
<tr>
<td>subscript</td>
<td>-ic</td>
<td>font</td>
<td>0</td>
<td>-ic/2</td>
<td>-ic/2</td>
<td>8000ic/1000</td>
</tr>
</tbody>
</table>

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 Con\TeX{}t 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 \texttt{mathnolimitsmode} larger that 15 is considered to be a factor for the subscript correction. This feature can be handy when experimenting.

### 6.8 Math spacing setting

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 \TeX{}book). The primitive names are a simple matter of combining two math atom types, but for completeness’ sake, here is the whole list:

\begin{verbatim}
\Umathordordspacing \Umathbininnerspacing
\Umathordopspacing \Umathrelordspacing
\Umathordbinspacing \Umathrelopspacing
\Umathordrelspacing \Umathrelbinspacing
\Umathordopenspacing \Umathrelclosespacing
\Umathordclosespacing \Umathrelopen spacing
\Umathordpunctspacing \Umathrelpunctspacing
\Umathordinnerspacing \Umathrelinnerspacing
\Umathoppordspacing \Umathopenordspacing
\Umathopordspacing \Umathopenordspacing
\Umathopinnerspacing \Umathopenpunctspacing
\Umathbinordspacing \Umathcloseordspacing
\Umathbinbinningterspacing \Umathcloseopen spacing
\Umathbinrelspacing \Umathclosebinspacing
\Umathbinopenspacing \Umathcloseclosespacing
\Umathbinpunctspacing
\end{verbatim}
\text{These parameters are of type } \backslash \text{muskip, so setting a parameter can be done like this:}

\backslash \text{Umathopordspacing}\textstyle=4\textmu \text{ plus } 2\textmu

\text{They are all initialized by } \textit{initex} \text{ to the values mentioned in the table in Chapter 18 of the T\textTeXbook.}

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

\text{Note 2: Careful readers will realise that there are also primitives for the items marked * in the T\textTeXbook. 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.}

\section*{6.9 Math accent handling}

\textit{Lua}\textTeX 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 \textbackslash \text{Umathaccent}.

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

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

\text{A simple example:}

\textbackslash \text{Umathaccent both fixed 0 0 "20D7 fixed 0 0 "20D7} \{\text{example}\}

\text{If a math top accent has to be placed and the accentee is a character and has a non-zero } \text{top_accent} \text{ value, then this value will be used to place the accent instead of the } \textbackslash \text{skewchar} \text{ kern used by T\textTeX82.}

\text{The } \text{top_accent} \text{ value represents a vertical line somewhere in the accentee. The accent will be shifted horizontally such that its own } \text{top_accent} \text{ 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 TeXbook), but if value that 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 criterion 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.

### 6.10 Math root extension

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 \mathradicaldegreebefore, \mathradicaldegreeafter, and \mathradicaldegreeraise. The degree will be typeset in \scriptscriptstyle.

### 6.11 Math kerning in 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, LuaTeX 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 TeX fonts), then LuaTeX 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.
- The default horizontal position is flat next to the base character.
- For superscripts, the italic correction of the base character is added.
- For a superscript, two vertical values are calculated: the bottom of the script (after shifting up), and the top of the base. For a subscript, the two values are the top of the (shifted down) script, and the bottom of the base.
- For each of these two locations:
− find the math kern value at this height for the base (for a subscript placement, this is the bottom_right corner, for a superscript placement the top_right corner)
− find the math kern value at this height for the script (for a subscript placement, this is the top_left corner, for a superscript placement the bottom_left corner)
− add the found values together to get a preliminary result.

• The horizontal kern to be applied is the smallest of the two results from previous step.

The math kern value at a specific height is the kern value that is specified by the next higher height and kern pair, or the highest one in the character (if there is no value high enough in the character), or simply zero (if the character has no math kern pairs at all).

6.12 Scripts on horizontally extensible items like arrows

The primitives \texttt{\Uunderdelimiter} and \texttt{\Uoverdelimiter} allow the placement of a subscript or superscript on an automatically extensible item and \texttt{\Udelimiterunder} and \texttt{\Udelimiterover} allow the placement of an automatically extensible item as a subscript or superscript on a nucleus. The input:

\begin{verbatim}
$\Uoverdelimiter 0 "2194 {\hbox{\strut overdelimiter}}$
$\Uunderdelimiter 0 "2194 {\hbox{\strut underdelimiter}}$
$\Udelimiterover 0 "2194 {\hbox{\strut delimiterover}}$
$\Udelimiterunder 0 "2194 {\hbox{\strut delimiterunder}}$
\end{verbatim}

will render this:

\begin{center}
\begin{tabular}{l}
\texttt{\Udelimiterover} & \texttt{\Udelimiterunder} \\
\texttt{\Uoverdelimiter} & \texttt{\Uunderdelimiter} \\
\end{tabular}
\end{center}

The vertical placements are controlled by \texttt{\Umathunderdelimiterbgap}, \texttt{\Umathunderdelim- itervgap}, \texttt{\Umathoverdelimiterbgap}, and \texttt{\Umathoverdelimitervgap} in a similar way as limit placements on large operators. The superscript in \texttt{\Uoverdelimiter} is typeset in a suitable scripted style, the subscript in \texttt{\Uunderdelimiter} is cramped as well.

These primitives accepts an option \texttt{width} specification. When used the also optional keywords \texttt{left}, \texttt{middle} and \texttt{right} will determine what happens when a requested size can't be met (which can happen when we step to successive larger variants).

An extra primitive \texttt{\Uhextensible} is available that can be used like this:

\begin{verbatim}
$\Uhextensible width 10cm 0 "2194$
\end{verbatim}

This will render this:

\begin{center}
\begin{tabular}{l}
\texttt{\Uhextensible}
\end{tabular}
\end{center}

Here you can also pass options, like:

\begin{verbatim}
$\Uhextensible width 1pt middle 0 "2194$
\end{verbatim}

This gives:
LuaTeX 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.

6.13 Extracting values

You can extract the components of a math character. Say that we have defined:

\textbackslash \texttt{Umathcode 1 2 3 4}

then

[\texttt{Umathcharclass1}] [\texttt{Umathcharfam1}] [\texttt{Umathcharslot1}]

will return:

[2] [3] [4]

These commands are provided as convenience. Before they came available you could do the following:

\texttt{\textbackslash def\textbackslash Umathcharclass{\textbackslash directlua{\texttt{tex.print(tex.getmathcode(token.scan_int())[1])}}}}
\texttt{\textbackslash def\textbackslash Umathcharfam {\textbackslash directlua{\texttt{tex.print(tex.getmathcode(token.scan_int())[2])}}}}
\texttt{\textbackslash def\textbackslash Umathcharslot {\textbackslash directlua{\texttt{tex.print(tex.getmathcode(token.scan_int())[3])}}}}

6.14 fractions

The \texttt{\textbackslash abovewithdelims} command accepts a keyword \texttt{exact}. When issued the extra space relative to the rule thickness is not added. One can of course use the \texttt{\textbackslash Umathfraction..gap} commands to influence the spacing. Also the rule is still positioned around the math axis.

$$ { {a} \textbackslash abovewithdelims() \texttt{ exact 4pt} {b} } $$

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 \texttt{\textbackslash Umathskewedfractionhgap} and \texttt{\textbackslash Umathskewedfractionvgap}.

The syntax used here is:

{ {1} \texttt{\textbackslash Uskewed / <options>} {2} }
{ {1} \texttt{\textbackslash Uskewedwithdelims / () <options>} {2} }

where the options can be \texttt{noaxis} and \texttt{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:

\begin{verbatim}
exact
x + \textfrac{a}{b} + x
x + \textfrac{1}{2} + x
x + (\textfrac{a}{b}) + x
x + (\textfrac{1}{2}) + x
\end{verbatim}
noaxis \( x + a/b + x \) \( x + 1/2 + x \) \( x + (a/b) + x \) \( x + (1/2) + x \)

exact noaxis \( x + a/b + x \) \( x + 1/2 + x \) \( x + (a/b) + x \) \( x + (1/2) + x \)

### 6.15 Last lines

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}

\relax

### 6.16 Other Math changes

#### 6.16.1 Verbose versions of single-character math commands

Lua\TeX{} defines six new primitives that have the same function as `^`, `_`, `$`, and `$$`:

<table>
<thead>
<tr>
<th>primitive</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Usuperscript</td>
<td>Duplicates the functionality of <code>^</code></td>
</tr>
<tr>
<td>\Usubscript</td>
<td>Duplicates the functionality of <code>_</code></td>
</tr>
<tr>
<td>\Ustartmath</td>
<td>Duplicates the functionality of <code>$</code>, when used in non-math mode.</td>
</tr>
<tr>
<td>\Ustopmath</td>
<td>Duplicates the functionality of <code>$</code>, when used in inline math mode.</td>
</tr>
<tr>
<td>\Ustartdisplaymath</td>
<td>Duplicates the functionality of <code>$$</code>, when used in non-math mode.</td>
</tr>
<tr>
<td>\Ustopdisplaymath</td>
<td>Duplicates the functionality of <code>$$</code>, when used in display math mode.</td>
</tr>
</tbody>
</table>

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).

#### 6.16.2 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.

### 6.17 Math surrounding skips

Inline math is surrounded by (optional) \mathsurround spacing but that is 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 \mathsurroundskip 20pt

<table>
<thead>
<tr>
<th>mode</th>
<th>x$x$x</th>
<th>x $x$</th>
<th>effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>xxx</td>
<td>x x x</td>
<td>obey \mathsurround when \mathsurroundskip is 0 pt</td>
</tr>
<tr>
<td>1</td>
<td>xxx</td>
<td>x x x</td>
<td>only add skip to the left</td>
</tr>
<tr>
<td>2</td>
<td>xxx</td>
<td>x x x</td>
<td>only add skip to the right</td>
</tr>
<tr>
<td>3</td>
<td>xxx</td>
<td>x x x</td>
<td>add skip to the left and right</td>
</tr>
<tr>
<td>4</td>
<td>xxx</td>
<td>x x x</td>
<td>ignore the skip setting, obey \mathsurround</td>
</tr>
<tr>
<td>5</td>
<td>xxx</td>
<td>x x x</td>
<td>disable all spacing around math</td>
</tr>
<tr>
<td>6</td>
<td>xxx</td>
<td>x x x</td>
<td>only apply \mathsurroundskip when also spacing</td>
</tr>
<tr>
<td>7</td>
<td>xxx</td>
<td>x x x</td>
<td>only apply \mathsurroundskip when no spacing</td>
</tr>
</tbody>
</table>

Method six omits the surround glue when there is (x)spacing glue present while method seven does the opposite, the glue is only applied when there is (x)space glue present too. Anything more fancier, 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).

### 6.17.1 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 that the characters as it depends on the fit as well as the fact if the used characters in the font have depth or height. Commands like (plain \TeX) \textbackslash big need use this feature. In \LuathX we provide a bit more control by three variants that supporting optional parameters height, depth and axis. The following example uses this:

\uleft height 30pt depth 10pt \udelimiter "0" "0" 000028 \quad x \quad\uleft height 30pt depth 10pt \udelimiter "0" "0" 000028
\umiddle height 40pt depth 15pt \udelimiter "0" "0" 002016 \quad x \quad\umiddle height 40pt depth 15pt \udelimiter "0" "0" 002016
\uright height 30pt depth 10pt \udelimiter "0" "0" 000029 \quad x \quad\uright height 30pt depth 10pt \udelimiter "0" "0" 000029
\uleft height 30pt depth 10pt axis \udelimiter "0" "0" 000028 \quad x \quad\uleft height 30pt depth 10pt axis \udelimiter "0" "0" 000028
\umiddle height 40pt depth 15pt axis \udelimiter "0" "0" 002016 \quad x \quad\umiddle height 40pt depth 15pt axis \udelimiter "0" "0" 002016
The keyword \textit{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 \texttt{noaxis} command can be used to prevent shifting over the axis.

You can influence the final class with the keyword \texttt{class} which will influence the spacing.

### 6.17.2 Fixed scripts

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

\begin{align*}
  d & \ \texttt{Umathsubshiftdown} \\
  u & \ \texttt{Umathsupshiftup} \\
  s & \ \texttt{Umathsubsupshiftdown}
\end{align*}

When we set \texttt{mathscripts}mode 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.

<table>
<thead>
<tr>
<th>mode</th>
<th>down</th>
<th>up</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>dynamic</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
<tr>
<td>1</td>
<td>d</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
<tr>
<td>2</td>
<td>s</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
<tr>
<td>3</td>
<td>s</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
<tr>
<td>4</td>
<td>d + (s - d)/2</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
<tr>
<td>5</td>
<td>d</td>
<td>CH\textsubscript{2} + CH\textsubscript{2} + CH\textsubscript{2}</td>
</tr>
</tbody>
</table>

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

### 6.17.3 Tracing

Because there are quite some math related parameters and values, it is possible to limit tracing. Only when \texttt{tracingassigns} and/or \texttt{tracingrestores} are set to 2 or more they will be traced.

### 6.17.4 Math options

The logic in the math engine is rather complex and there are often no universal solutions (read: what works out well for one font, fails for another). Therefore some variations in the implementation will be driven by options for which a new primitive \texttt{mathoption} has been introduced (so
that we don’t end up with many new commands). The approach of options also permits us to see what effect a specific solution has.

6.17.4.1 \texttt{\textbackslash mathoption old}

This option was introduced for testing purposes when the math engine got split code paths and it forces the engine to treat new fonts as old ones with respect to italic correction etc. There are no guarantees given with respect to the final result and unexpected side effects are not seen as bugs as they relate to font properties.

The \texttt{oldmath} boolean flag in the Lua font table is the official way to force old treatment as it’s bound to fonts.

6.17.4.2 \texttt{\textbackslash mathoption noitaliccompensation}

This option compensates placement for characters with a built-in italic correction.

\begin{verbatim}
{\showboxes\int}\quad
{\showboxes\int_{|}^{|}}\quad
{\showboxes\int\limits_{|}^{|}}
\end{verbatim}

Gives (with computer modern that has such italics):

\begin{verbatim}
∫ H__ ∫ H__ ∫ H__
\end{verbatim}

6.17.4.3 \texttt{\textbackslash mathoption nocharitalic}

When two characters follow each other italic correction can interfere. The following example shows what this option does:

\begin{verbatim}
\catcode"1D443=11
\catcode"1D444=11
\catcode"1D445=11
P( PP PQR
\end{verbatim}

Gives (with computer modern that has such italics):

\begin{verbatim}
P(PPPQR P(PPPQR
\end{verbatim}
6.17.4.4 \texttt{mathoption useoldfractionscaling}

This option has been introduced as solution for tracker item 604 for fuzzy cases around either or not present fraction related settings for new fonts.
7 Nodes

7.1 LUA node representation

\TeX's nodes are represented in Lua as userdata object with a variable set of fields. In the following syntax tables, such the type of such a userdata object is represented as \texttt{(node)}.

The current return value of \texttt{node.types()} is: \texttt{hlist (0), vlist (1), rule (2), ins (3), mark (4), adjust (5), boundary (6), disc (7), whatsit (8), local_par (9), dir (10), math (11), glue (12), kern (13), penalty (14), unset (15), style (16), choice (17), noad (18), radical (19), fraction (20), accent (21), fence (22), math_char (23), sub_box (24), sub_mlist (25), math_text_char (26), delim (27), margin_kern (28), glyph (29), align_record (30), pseudo_file (31), pseudo_line (32), page_insert (33), split_insert (34), expr_stack (35), nested_list (36), span (37), attribute (38), glue_spec (39), attribute_list (40), temp (41), align_stack (42), movement_stack (43), if_stack (44), unhyphenated (45), hyphenated (46), delta (47), passive (48), shape (49).

The \texttt{last}nodetype primitive is \TeX compliant. The valid range is still \([-1, 15]\) and glyph nodes (formerly known as char nodes) have number 0 while ligature nodes are mapped to 7. That way macro packages can use the same symbolic names as in traditional \TeX. Keep in mind that these \TeX node numbers are different from the real internal ones and that there are more \TeX node types than 15.

You can ask for a list of fields with the \texttt{node.fields} (which takes an id) and for valid subtypes with \texttt{node.subtypes} (which takes a string because eventually we might support more used enumerations).

7.1.1 Attributes

The newly introduced attribute registers are non-trivial, because the value that is attached to a node is essentially a 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, but for completeness, here is the low-level interface.

7.1.1.1 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:

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>next</td>
<td>node</td>
<td>pointer to the first attribute</td>
</tr>
</tbody>
</table>

7.1.1.2 attribute 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.
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.

### 7.1.2 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:

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>next</td>
<td>node</td>
<td>the next node in a list, or nil</td>
</tr>
<tr>
<td>id</td>
<td>number</td>
<td>the node's type (id) number</td>
</tr>
<tr>
<td>subtype</td>
<td>number</td>
<td>the node subtype identifier</td>
</tr>
</tbody>
</table>

The `subtype` is sometimes just a stub entry. 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.

#### 7.1.2.1 hlist nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = unknown, 1 = line, 2 = box, 3 = indent, 4 = alignment, 5 = cell, 6 = equation, 7 = equationnumber</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width of the box</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height of the box</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth of the box</td>
</tr>
<tr>
<td>shift</td>
<td>number</td>
<td>a displacement perpendicular to the character progression direction</td>
</tr>
<tr>
<td>glue_order</td>
<td>number</td>
<td>a number in the range [0, 4], indicating the glue order</td>
</tr>
<tr>
<td>glue_set</td>
<td>number</td>
<td>the calculated glue ratio</td>
</tr>
<tr>
<td>glue_sign</td>
<td>number</td>
<td>0 = normal, 1 = stretching, 2 = shrinking</td>
</tr>
<tr>
<td>head/list</td>
<td>node</td>
<td>the first node of the body of this list</td>
</tr>
<tr>
<td>dir</td>
<td>string</td>
<td>the direction of this box, see 7.1.2.15</td>
</tr>
</tbody>
</table>

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.
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.

### 7.1.2.2 vlist nodes

This node is similar to hlist, except that ‘shift’ is a displacement perpendicular to the line progression direction, and ‘subtype’ only has the values 0, 4, and 5.

### 7.1.2.3 rule nodes

Contrary to traditional TeX, LuaTeX has more subtypes because we also use rules to store reusable objects and images. User nodes are invisible and can be intercepted by a callback.

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = normal, 1 = box, 2 = image, 3 = empty, 4 = user, 5 = over, 6 = under, 7 = fraction, 8 = radical</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width of the rule where the special value −1073741824 is used for ‘running’ glue dimensions</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height of the rule (can be negative)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth of the rule (can be negative)</td>
</tr>
<tr>
<td>dir</td>
<td>string</td>
<td>the direction of this rule, see 7.1.2.15</td>
</tr>
<tr>
<td>index</td>
<td>number</td>
<td>an optional index that can be referred to</td>
</tr>
</tbody>
</table>

### 7.1.2.4 ins nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>the insertion class</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>cost</td>
<td>number</td>
<td>the penalty associated with this insert</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>height of the insert</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>depth of the insert</td>
</tr>
<tr>
<td>head/list</td>
<td>node</td>
<td>the first node of the body of this insert</td>
</tr>
</tbody>
</table>

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 be result. You can use list instead (often in functions you want to use local variable with similar names and both names are equally sensible).

### 7.1.2.5 mark nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>unused</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
</tbody>
</table>
### 7.1.2.6 Adjust nodes

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = normal, 1 = pre</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>head/list</td>
<td>node</td>
<td>adjusted material</td>
</tr>
</tbody>
</table>

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 result.

### 7.1.2.7 Disc nodes

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = discretionary, 1 = explicit, 2 = automatic, 3 = regular, 4 = first, 5 = second</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>pre</td>
<td>node</td>
<td>pointer to the pre-break text</td>
</tr>
<tr>
<td>post</td>
<td>node</td>
<td>pointer to the post-break text</td>
</tr>
<tr>
<td>replace</td>
<td>node</td>
<td>pointer to the no-break text</td>
</tr>
<tr>
<td>penalty</td>
<td>number</td>
<td>the penalty associated with the break, normally \hyphenpenalty or \exhyphenpenalty</td>
</tr>
</tbody>
</table>

The subtype numbers 4 and 5 belong to the ‘of-f-ice’ explanation given elsewhere.

These disc nodes are kind of special as at some point they also keep information about break-points 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:

```lua
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 Lua\TeX{} 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 an node but part of the disc data structure (so freeing it again might crash Lua\TeX{}).

### 7.1.2.8 Math nodes

<table>
<thead>
<tr>
<th>Field</th>
<th>Type</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = beginmath, 1 = endmath</td>
</tr>
</tbody>
</table>
attr node list of attributes
surround number width of the \textbackslash mathsurround \textbackslash kern

There is a set of extra fields that concern the associated glue: width, stretch, stretch_order, shrink and shrink_order. These are all numbers.

### 7.1.2.9 glue nodes

Skips are about the only type of data objects in traditional \texttt{\LaTeX} that are not a simple value. The structure that represents the glue components of a skip is called a glue_spec, and it has the following accessible fields:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>number</td>
<td>the horizontal or vertical displacement</td>
</tr>
<tr>
<td>stretch</td>
<td>number</td>
<td>extra (positive) displacement or stretch amount</td>
</tr>
<tr>
<td>stretch_order</td>
<td>number</td>
<td>factor applied to stretch amount</td>
</tr>
<tr>
<td>shrink</td>
<td>number</td>
<td>extra (negative) displacement or shrink amount</td>
</tr>
<tr>
<td>shrink_order</td>
<td>number</td>
<td>factor applied to shrink amount</td>
</tr>
</tbody>
</table>

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 \texttt{\textit{effective\_glue}} function that takes a glue node and a parent (hlist or vlist) returns the effective width of that glue item.

A glue_spec node is a special kind of node that is used for storing a set of glue values in registers. Originally they were also used to store properties of glue nodes (using a system of reference counts) but we now keep these properties in the glue nodes themselves, which gives a cleaner interface to Lua.

The indirect spec approach was in fact an optimization in the original \texttt{\LaTeX} code. First of all it can save quite some memory because all these spaces that become glue now share the same specification (only the reference count is incremented), and zero testing is also a bit faster because only the pointer has to be checked (this is no longer true for engines that implement for instance protrusion where we really need to ensure that zero is zero when we test for bounds). Another side effect is that glue specifications are read-only, so in the end copies need to be made when they are used from Lua (each assignment to a field can result in a new copy). So in the end the advantages of sharing are not that high (and nowadays memory is less an issue, also given that a glue node is only a few memory words larger than a spec).

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = userskip, 1 = lineskip, 2 = baselineskip, 3 = parskip, 4 = abovedisplay skip, 5 = belowdisplay skip, 6 = abovedisplayshortskip, 7 = belowdisplayshortskip, 8 = leftskip, 9 = rightskip, 10 = topskip, 11 = splittopskip, 12 = tabskip, 13 = spaceskip, 14 = xspaceskip, 15 = parfillskip, 16 = mathskip, 17 = thinmuskip, 18 = medmuskip, 19 = thickmuskip, 98 = conditionalmathskip, 99 = muglue, 100 = leaders, 101 = cleaders, 102 = xleaders, 103 = gleaders</td>
</tr>
</tbody>
</table>
attr node list of attributes
leader node pointer to a box or rule for leaders

In addition there are the width, stretch stretch_order, shrink, and shrink_order fields. 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.

A regular word space also results in a spaceskip subtype (this used to be a userskip with subtype zero).

### 7.1.2.10 kern nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = fontkern, 1 = userkern, 2 = accentkern, 3 = italiccorrection</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>kern</td>
<td>number</td>
<td>fixed horizontal or vertical advance</td>
</tr>
</tbody>
</table>

### 7.1.2.11 penalty nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>not used</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>penalty</td>
<td>number</td>
<td>the penalty value</td>
</tr>
</tbody>
</table>

### 7.1.2.12 glyph nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>bitfield</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>char</td>
<td>number</td>
<td>the character index in the font</td>
</tr>
<tr>
<td>font</td>
<td>number</td>
<td>the font identifier</td>
</tr>
<tr>
<td>lang</td>
<td>number</td>
<td>the language identifier</td>
</tr>
<tr>
<td>left</td>
<td>number</td>
<td>the frozen \lefthyphenmin value</td>
</tr>
<tr>
<td>right</td>
<td>number</td>
<td>the frozen \righthyphenmin value</td>
</tr>
<tr>
<td>uchyp</td>
<td>boolean</td>
<td>the frozen \uchyph value</td>
</tr>
<tr>
<td>components</td>
<td>node</td>
<td>pointer to ligature components</td>
</tr>
<tr>
<td>xoffset</td>
<td>number</td>
<td>a virtual displacement in horizontal direction</td>
</tr>
<tr>
<td>yoffset</td>
<td>number</td>
<td>a virtual displacement in vertical direction</td>
</tr>
<tr>
<td>xadvance</td>
<td>number</td>
<td>an additional advance after the glyph (experimental)</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the (original) width of the character</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the (original) height of the character</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the (original) depth of the character</td>
</tr>
<tr>
<td>expansion_factor</td>
<td>number</td>
<td>the to be applied expansion_factor</td>
</tr>
</tbody>
</table>

The width, height and depth values are read-only. The expansion_factor is assigned in the parbuilder and used in the backend.
A warning: never assign a node list to the components field unless you are sure its internal link structure is correct, otherwise an error may be result. Valid bits for the subtype field are:

<table>
<thead>
<tr>
<th>bit</th>
<th>meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>character</td>
</tr>
<tr>
<td>1</td>
<td>ligature</td>
</tr>
<tr>
<td>2</td>
<td>ghost</td>
</tr>
<tr>
<td>3</td>
<td>left</td>
</tr>
<tr>
<td>4</td>
<td>right</td>
</tr>
</tbody>
</table>

See section 4.1 for a detailed description of the subtype field.

The expansion_factor has been introduced as part of the separation between font- 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 pdflatex 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.

### 7.1.2.13 boundary nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = cancel, 1 = user, 2 = protrusion, 3 = word</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>value</td>
<td>number</td>
<td>values 0-255 are reserved</td>
</tr>
</tbody>
</table>

This node relates to the \noboundary, \boundary, \protrusionboundary and \wordboundary primitives.

### 7.1.2.14 local_par nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>pen_inter</td>
<td>number</td>
<td>local interline penalty (from \localinterlinepenalty)</td>
</tr>
<tr>
<td>pen_broken</td>
<td>number</td>
<td>local broken penalty (from \localbrokenpenalty)</td>
</tr>
<tr>
<td>dir</td>
<td>string</td>
<td>the direction of this par. see 7.1.2.15</td>
</tr>
<tr>
<td>box_left</td>
<td>node</td>
<td>the \localleftbox</td>
</tr>
<tr>
<td>box_left_width</td>
<td>number</td>
<td>width of the \localleftbox</td>
</tr>
<tr>
<td>box_right</td>
<td>node</td>
<td>the \localrightbox</td>
</tr>
<tr>
<td>box_right_width</td>
<td>number</td>
<td>width of the \localrightbox</td>
</tr>
</tbody>
</table>
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 be result.

### 7.1.2.15 dir nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>dir</td>
<td>string</td>
<td>the direction (but see below)</td>
</tr>
<tr>
<td>level</td>
<td>number</td>
<td>nesting level of this direction</td>
</tr>
</tbody>
</table>

A note on dir strings. Direction specifiers are three-letter combinations of T, B, R, and L. These are built up out of three separate items:

- the first is the direction of the ‘top’ of paragraphs.
- the second is the direction of the ‘start’ of lines.
- the third is the direction of the ‘top’ of glyphs.

However, only four combinations are accepted: TLT, TRT, RTT, and LTL.

Inside actual dir whatsit nodes, the representation of dir is not a three-letter but a four-letter combination. The first character in this case is always either + or -, indicating whether the value is pushed or popped from the direction stack.

### 7.1.2.16 margin_kern nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the advance of the kern</td>
</tr>
<tr>
<td>glyph</td>
<td>node</td>
<td>the glyph to be used</td>
</tr>
</tbody>
</table>

### 7.1.3 Math nodes

These are the so-called ‘nood’s and the nodes that are specifically associated with math processing. Most of these nodes contain subnodes so that the list of possible fields is actually quite small. First, the subnodes:

#### 7.1.3.1 Math kernel subnodes

Many object fields in math mode are either simple characters in a specific family or math lists or node lists. There are four associated subnodes that represent these cases (in the following node descriptions these are indicated by the word <kernel>).

The next and prev fields for these subnodes are unused.

#### 7.1.3.1.1 math_char and math_text_char subnodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
</tbody>
</table>
The **math_char** is the simplest subnode field, it contains the character and family for a single glyph object. 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).

### 7.1.3.1.2 sub_box and sub_mlist subnodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>head/list</td>
<td>node</td>
<td>list of nodes</td>
</tr>
</tbody>
</table>

These two subnode types are used for subsidiary list items. For **sub_box**, the head points to a ‘normal’ vbox or hbox. For **sub_mlist**, the head points to a math list that is yet to be converted.

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 result.

### 7.1.3.2 Math delimiter subnode

There is a fifth subnode type that is used exclusively for delimiter fields. As before, the next and prev fields are unused.

### 7.1.3.2.1 delim subnodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>small_char</td>
<td>number</td>
<td>character index of base character</td>
</tr>
<tr>
<td>small_fam</td>
<td>number</td>
<td>family number of base character</td>
</tr>
<tr>
<td>large_char</td>
<td>number</td>
<td>character index of next larger character</td>
</tr>
<tr>
<td>large_fam</td>
<td>number</td>
<td>family number of next larger character</td>
</tr>
</tbody>
</table>

The fields **large_char** and **large_fam** can be zero, in that case the font that is sed for the **small_fam** is expected to provide the large version as an extension to the **small_char**.

### 7.1.3.3 Math core nodes

First, there are the objects (the TeXbook calls then ‘atoms’) that are associated with the simple math objects: ord, op, bin, rel, open, close, punct, inner, over, under, vcent. These all have the same fields, and they are combined into a single node type with separate subtypes for differentiation.

### 7.1.3.3.1 simple nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = ord, 1 = opdisplaylimits, 2 = oplimits, 3 = opnolimits, 4 = bin, 5 = rel, 6 = open, 7 = close, 8 = punct, 9 = inner, 10 = under, 11 = over, 12 = vcenter</td>
</tr>
</tbody>
</table>
7.1.3.3.2 accent nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = bothflexible, 1 = fixedtop, 2 = fixedbottom, 3 = fixedboth</td>
</tr>
<tr>
<td>nucleus</td>
<td>kernel node</td>
<td>base</td>
</tr>
<tr>
<td>sub</td>
<td>kernel node</td>
<td>subscript</td>
</tr>
<tr>
<td>sup</td>
<td>kernel node</td>
<td>superscript</td>
</tr>
<tr>
<td>accent</td>
<td>kernel node</td>
<td>top accent</td>
</tr>
<tr>
<td>bot_accent</td>
<td>kernel node</td>
<td>bottom accent</td>
</tr>
<tr>
<td>fraction</td>
<td>number</td>
<td>larger step criterium (divided by 1000)</td>
</tr>
</tbody>
</table>

7.1.3.3.3 style nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>style</td>
<td>string</td>
<td>contains the style</td>
</tr>
</tbody>
</table>

There are eight possibilities for the string value: one of ‘display’, ‘text’, ‘script’, or ‘scriptscript’. Each of these can have a trailing ‘ ’ to signify ‘cramped’ styles.

7.1.3.3.4 choice nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>display</td>
<td>node</td>
<td>list of display size alternatives</td>
</tr>
<tr>
<td>text</td>
<td>node</td>
<td>list of text size alternatives</td>
</tr>
<tr>
<td>script</td>
<td>node</td>
<td>list of scriptsize alternatives</td>
</tr>
<tr>
<td>scriptscrip</td>
<td>node</td>
<td>list of scriptscrip size alternatives</td>
</tr>
</tbody>
</table>

Warning: never assign a node list to the display, text, script, or scriptscrip field unless you are sure its internal link structure is correct, otherwise an error may be result.

7.1.3.3.5 radical nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = radical, 1 = uradical, 2 = uroot, 3 = uunderdelimiter, 4 = uoverdelimiter, 5 = udelimiterunder, 6 = udelimiterover</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>nucleus</td>
<td>kernel node</td>
<td>base</td>
</tr>
<tr>
<td>sub</td>
<td>kernel node</td>
<td>subscript</td>
</tr>
<tr>
<td>sup</td>
<td>kernel node</td>
<td>superscript</td>
</tr>
<tr>
<td>left</td>
<td>delimiter node</td>
<td></td>
</tr>
</tbody>
</table>
degree kernel node only set by \textbackslash Uroot
width number required width
options number bitset of rendering options

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 may be result.

7.1.3.3.6 fraction nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>(optional) width of the fraction</td>
</tr>
<tr>
<td>num</td>
<td>kernel node</td>
<td>numerator</td>
</tr>
<tr>
<td>denom</td>
<td>kernel node</td>
<td>denominator</td>
</tr>
<tr>
<td>left</td>
<td>delimiter node</td>
<td>left side symbol</td>
</tr>
<tr>
<td>right</td>
<td>delimiter node</td>
<td>right side symbol</td>
</tr>
<tr>
<td>middle</td>
<td>delimiter node</td>
<td>middle symbol</td>
</tr>
<tr>
<td>options</td>
<td>number</td>
<td>bitset of rendering options</td>
</tr>
</tbody>
</table>

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 may be result.

7.1.3.3.7 fence nodes

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>subtype</td>
<td>number</td>
<td>0 = unset, 1 = left, 2 = middle, 3 = right</td>
</tr>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>delim</td>
<td>delimiter node</td>
<td>delimiter specification</td>
</tr>
<tr>
<td>italic</td>
<td>number</td>
<td>italic correction</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>required height</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>required depth</td>
</tr>
<tr>
<td>options</td>
<td>number</td>
<td>bitset of rendering options</td>
</tr>
<tr>
<td>class</td>
<td>number</td>
<td>spacing related class</td>
</tr>
</tbody>
</table>

Warning: some of these fields are used by the renderer and might get adapted in the process.

7.1.4 whatsit nodes

Whatsit nodes come in many subtypes that you can ask for by running node.whatsits():
onopen (0), write (1), close (2), special (3), save_pos (6), late_lua (7), user_defined (8),
pdf_literal (16), pdf_refobj (17), pdf_annot (18), pdf_start_link (19), pdf_end_link (20),
pdf_dest (21), pdf_action (22), pdf_thread (23), pdf_start_thread (24), pdf_end_thread (25),
pdf_thread_data (26), pdf_link_data (27), pdf_colorstack (28), pdf_setmatrix (29),
pdf_save (30), pdf_restore (31), fake (100).
7.1.4.1 front-end whatsits

7.1.4.1.1 open whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>stream</td>
<td>number</td>
<td>\TeX{}’s stream id number</td>
</tr>
<tr>
<td>name</td>
<td>string</td>
<td>file name</td>
</tr>
<tr>
<td>ext</td>
<td>string</td>
<td>file extension</td>
</tr>
<tr>
<td>area</td>
<td>string</td>
<td>file area (this may become obsolete)</td>
</tr>
</tbody>
</table>

7.1.4.1.2 write whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>stream</td>
<td>number</td>
<td>\TeX{}’s stream id number</td>
</tr>
<tr>
<td>data</td>
<td>table</td>
<td>a table representing the token list to be written</td>
</tr>
</tbody>
</table>

7.1.4.1.3 close whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>stream</td>
<td>number</td>
<td>\TeX{}’s stream id number</td>
</tr>
</tbody>
</table>

7.1.4.1.4 user_defined whatsits

User-defined whatsit nodes can only be created and handled from Lua code. In effect, they are an extension to the extension mechanism. The \LaTeX{} engine will simply step over such whatsit nodes without ever looking at the contents.

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>user_id</td>
<td>number</td>
<td>id number</td>
</tr>
<tr>
<td>type</td>
<td>number</td>
<td>type of the value</td>
</tr>
<tr>
<td>value</td>
<td>number</td>
<td>a Lua number</td>
</tr>
<tr>
<td>node</td>
<td>number</td>
<td>a node list</td>
</tr>
<tr>
<td>string</td>
<td>number</td>
<td>a Lua string</td>
</tr>
<tr>
<td>table</td>
<td>number</td>
<td>a Lua table</td>
</tr>
</tbody>
</table>

The type can have one of six distinct values. The number is the ascii value if the first character if the type name (so you can use string.byte("l") instead of 108).

<table>
<thead>
<tr>
<th>value</th>
<th>meaning</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
<td>a</td>
<td>list of attributes (a node list)</td>
</tr>
<tr>
<td>100</td>
<td>d</td>
<td>a Lua number</td>
</tr>
<tr>
<td>108</td>
<td>l</td>
<td>a Lua value (table, number, boolean, etc)</td>
</tr>
</tbody>
</table>
110 n a node list
115 s a Lua string
116 t a Lua token list in Lua table form (a list of triplets)

7.1.4.1.5 save_pos whatsits

field type explanation
attr node list of attributes

7.1.4.1.6 late_lua whatsits

field type explanation
attr node list of attributes
data string data to execute
string string data to execute
name string the name to use for Lua error reporting

The difference between data and string is that on assignment, the data field is converted to a token list, cf. use as \latelua. The string version is treated as a literal string.

7.1.4.2 DVI backend whatsits

7.1.4.3 special whatsits

field type explanation
attr node list of attributes
data string the \special information

7.1.4.4 PDF backend whatsits

7.1.4.4.1 pdf_literal whatsits

field type explanation
attr node list of attributes
mode number the ‘mode’ setting of this literal
data string the \pdfliteral information

Possible mode values are:

value pdf\TeX\ keyword
0 setorigin
1 page
2 direct
3 raw

The higher the number, the less checking and the more you can run into troubles. Especially the raw variant can produce bad pdf so you can best check what you generate.
7.1.4.4.2 pdf_refobj whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>objnum</td>
<td>number</td>
<td>the referenced pdf object number</td>
</tr>
</tbody>
</table>

7.1.4.4.3 pdf_annot whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width (not used in calculations)</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height (not used in calculations)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth (not used in calculations)</td>
</tr>
<tr>
<td>objnum</td>
<td>number</td>
<td>the referenced pdf object number</td>
</tr>
<tr>
<td>data</td>
<td>string</td>
<td>the annotation data</td>
</tr>
</tbody>
</table>

7.1.4.4.4 pdf_start_link whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width (not used in calculations)</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height (not used in calculations)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth (not used in calculations)</td>
</tr>
<tr>
<td>objnum</td>
<td>number</td>
<td>the referenced pdf object number</td>
</tr>
<tr>
<td>link_attr</td>
<td>table</td>
<td>the link attribute token list</td>
</tr>
<tr>
<td>action</td>
<td>node</td>
<td>the action to perform</td>
</tr>
</tbody>
</table>

7.1.4.4.5 pdf_end_link whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td></td>
</tr>
</tbody>
</table>

7.1.4.4.6 pdf_dest whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width (not used in calculations)</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height (not used in calculations)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth (not used in calculations)</td>
</tr>
<tr>
<td>named_id</td>
<td>number</td>
<td>is the dest_id a string value?</td>
</tr>
<tr>
<td>dest_id</td>
<td>number</td>
<td>the destination id</td>
</tr>
<tr>
<td>dest_type</td>
<td>string</td>
<td>the destination name</td>
</tr>
<tr>
<td>xyz_zoom</td>
<td>number</td>
<td>the zoom factor (times 1000)</td>
</tr>
<tr>
<td>objnum</td>
<td>number</td>
<td>the pdf object number</td>
</tr>
</tbody>
</table>
7.1.4.4.7 pdf_action whatsits

These are a special kind of item that only appears inside pdf start link objects.

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>action_type</td>
<td>number</td>
<td>the kind of action involved</td>
</tr>
<tr>
<td>action_id</td>
<td>number or string</td>
<td>token list reference or string</td>
</tr>
<tr>
<td>named_id</td>
<td>number</td>
<td>the index of the destination</td>
</tr>
<tr>
<td>file</td>
<td>string</td>
<td>the target filename</td>
</tr>
<tr>
<td>new_window</td>
<td>number</td>
<td>the window state of the target</td>
</tr>
<tr>
<td>data</td>
<td>string</td>
<td>the name of the destination</td>
</tr>
</tbody>
</table>

Valid action types are:

0  page
1  goto
2  thread
3  user

Valid window types are:

0  notset
1  new
2  nonew

7.1.4.4.8 pdf_thread whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width (not used in calculations)</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height (not used in calculations)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth (not used in calculations)</td>
</tr>
<tr>
<td>named_id</td>
<td>number</td>
<td>is thread_id a string value?</td>
</tr>
<tr>
<td>thread_id</td>
<td>number</td>
<td>the thread id</td>
</tr>
<tr>
<td>string</td>
<td>the thread name</td>
<td></td>
</tr>
<tr>
<td>thread_attr</td>
<td>number</td>
<td>extra thread information</td>
</tr>
</tbody>
</table>

7.1.4.4.9 pdf_start_thread whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the width (not used in calculations)</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the height (not used in calculations)</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the depth (not used in calculations)</td>
</tr>
<tr>
<td>named_id</td>
<td>number</td>
<td>is thread_id a string value?</td>
</tr>
<tr>
<td>thread_id</td>
<td>number</td>
<td>the thread id</td>
</tr>
<tr>
<td>string</td>
<td>the thread name</td>
<td></td>
</tr>
<tr>
<td>thread_attr</td>
<td>number</td>
<td>extra thread information</td>
</tr>
</tbody>
</table>
### 7.1.4.4.10 pdf_end_thread whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td></td>
</tr>
</tbody>
</table>

### 7.1.4.4.11 pdf_colorstack whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>stack</td>
<td>number</td>
<td>colorstack id number</td>
</tr>
<tr>
<td>command</td>
<td>number</td>
<td>command to execute</td>
</tr>
<tr>
<td>data</td>
<td>string</td>
<td>data</td>
</tr>
</tbody>
</table>

### 7.1.4.4.12 pdf_setmatrix whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
<tr>
<td>data</td>
<td>string</td>
<td>data</td>
</tr>
</tbody>
</table>

### 7.1.4.4.13 pdf_save whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
</tbody>
</table>

### 7.1.4.4.14 pdf_restore whatsits

<table>
<thead>
<tr>
<th>field</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>node</td>
<td>list of attributes</td>
</tr>
</tbody>
</table>

### 7.2 The node library

The node library contains functions that facilitate dealing with (lists of) nodes and their values. They allow you to create, alter, copy, delete, and insert LuaTeX node objects, the core objects within the typesetter.

LuaTeX nodes are represented in Lua as userdata with the metadata type `luatex.node`. 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 `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`, but it is most important when dealing with ‘whatsits’, because they are differentiated solely based on their `subtype`. 
The other available fields depend on the id (and for ‘whatsits’, the subtype) of the node. Further details on the various fields and their meanings are given in chapter 7.

Support for unset (alignment) nodes is partial: they can be queried and modified from Lua code, but not created.

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.

At the moment, memory management of nodes should still 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.

There are statistics available with regards to the allocated node memory, which can be handy for tracing.

### 7.2.1 Node handling functions

#### 7.2.1.1 node.is_node

<boolean> t =
node.is_node(<any> item)

This function returns true if the argument is a userdata object of type <node>.

#### 7.2.1.2 node.types

<table> t =
node.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.

#### 7.2.1.3 node.whatsits

<table> t =
node.whatsits()

\TeX’s ‘whatsits’ all have the same id. The various subtypes are defined by their subtype fields. The function is much like node.types, except that it provides an array of subtype mappings.

#### 7.2.1.4 node.id

<number> id =
node.id(<string> type)

This converts a single type name to its internal numeric representation.

7.2.1.5 node.subtype

<number> subtype =
node.subtype(<string> type)

This converts a single whatsit name to its internal numeric representation (subtype).

7.2.1.6 node.type

<string> type =
node.type(<any> n)

In the argument is a number, then this 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.

7.2.1.7 node.fields

<table> t =
node.fields(<number> id)
<table> t =
node.fields(<number> id, <number> subtype)

This function returns an array of valid field names for a particular type of node. If you want to get the valid fields for a ‘whatsit’, you have to supply the second argument also. In other cases, any given second argument will be silently ignored.

This function accepts string `id` and `subtype` values as well.

7.2.1.8 node.has_field

<boolean> t =
node.has_field(<node> n, <string> field)

This function returns a boolean that is only true if `n` is actually a node, and it has the field.

7.2.1.9 node.new

<node> n =
node.new(<number> id)
<node> n =
node.new(<number> id, <number> subtype)

Creates a new node. All of the new node’s fields are initialized to either zero or `nil` except for `id` and `subtype` (if supplied). If you want to create a new whatsit, then the second argument is
required, otherwise it need not be present. As with all node functions, this function creates a node on the \TeX{} level.

This function accepts string \texttt{id} and \texttt{subtype} values as well.

### 7.2.1.10 \texttt{node.free} and \texttt{node.flush_node}

\begin{verbatim}
<nodename> next =
    node.free(<nodename> n)
flush_node(<nodename> n)
\end{verbatim}

Removes the node \texttt{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.

The \texttt{free} function returns the next field of the freed node, while the \texttt{flush_node} alternative returns nothing.

### 7.2.1.11 \texttt{node.flush_list}

\begin{verbatim}
nodename.flush_list(<nodename> n)
\end{verbatim}

Removes the node list \texttt{n} and the complete node list following \texttt{n} from \TeX{}’s memory. 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.

### 7.2.1.12 \texttt{node.copy}

\begin{verbatim}
<nodename> m =
    node.copy(<nodename> n)
\end{verbatim}

Creates a deep copy of node \texttt{n}, including all nested lists as in the case of a hlist or vlist node. Only the next field is not copied.

### 7.2.1.13 \texttt{node.copy_list}

\begin{verbatim}
<nodename> m =
    node.copy_list(<nodename> n)
<nodename> m =
    node.copy_list(<nodename> n, <nodename> m)
\end{verbatim}

Creates a deep copy of the node list that starts at \texttt{n}. If \texttt{m} is also given, the copy stops just before node \texttt{m}.

Note that you cannot copy attribute lists this way, specialized functions for dealing with attribute lists will be provided later but are not there yet. However, there is normally no need to copy attribute lists as when you do assignments to the \texttt{attr} field or make changes to specific attributes, the needed copying and freeing takes place automatically.
7.2.1.14 node.next

```plaintext
<node> m = node.next(<node> n)
```

Returns the node following this node, or nil if there is no such node.

7.2.1.15 node.prev

```plaintext
<node> m = node.prev(<node> n)
```

Returns the node preceding this node, or nil if there is no such node.

7.2.1.16 node.current_attr

```plaintext
<node> m = node.current_attr()
```

Returns the currently active list of attributes, if there is one.

The intended usage of `current_attr` is as follows:

```plaintext
local x1 = node.new("glyph")
x1.attr = node.current_attr()
local x2 = node.new("glyph")
x2.attr = node.current_attr()
```

or:

```plaintext
local x1 = node.new("glyph")
local x2 = node.new("glyph")
local ca = node.current_attr()
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.

Note: this function is somewhat experimental, and it returns the *actual* attribute list, not a copy thereof. Therefore, changing any of the attributes in the list will change these values for all nodes that have the current attribute list assigned to them.

7.2.1.17 node.hpack

```plaintext
<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)

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.

Caveat: at this moment, 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!

7.2.1.18 node.vpack

<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)

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.

The second return value is the badness of the generated box.

See the description of node.hpack() for a few memory allocation caveats.

7.2.1.19 node.dimensions, node.rangedimensions

<number> w, <number> h, <number> d =
    node.dimensions(<node> n)
<number> w, <number> h, <number> d =
    node.dimensions(<node> n, <string> dir)
<number> w, <number> h, <number> d =
    node.dimensions(<node> n, <node> t)
<number> w, <number> h, <number> d =
    node.dimensions(<node> n, <node> t, <string> dir)

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:
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 \texttt{\textbackslash box 0} was used as-is:

\setbox0 = \hbox to 20pt {a b}
\directlua{print (node.dimensions(}
\hspace{10pt} tex.box[0].glue_set, \hspace{10pt}
\hspace{10pt} tex.box[0].glue_sign, \hspace{10pt}
\hspace{10pt} tex.box[0].glue_order, \hspace{10pt}
\hspace{10pt} tex.box[0].head.next, \hspace{10pt}
\hspace{10pt} 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 \texttt{hpack} with \texttt{dimensions}.

The second alternative saves a few lookups and can be more convenient in some cases:

\begin{verbatim}
<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)
\end{verbatim}

**7.2.1.20 node.mlist_to_hlist**

<node> h =
    node.mlist_to_hlist(<node> n, <string> display_type, <boolean> penalties)

This runs the internal mlist to hlist conversion, converting the math list in \texttt{n} into the horizontal list \texttt{h}. The interface is exactly the same as for the callback \texttt{mlist_to_hlist}.

**7.2.1.21 node.slide**

<node> m =
node.slide(<node> n)

Returns the last node of the node list that starts at n. As a side-effect, it also creates a reverse chain of prev pointers between nodes.

### 7.2.1.22 node.tail

<node> m =
   node.tail(<node> n)

Returns the last node of the node list that starts at n.

### 7.2.1.23 node.length

<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.

### 7.2.1.24 node.count

<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.

### 7.2.1.25 node.traverse

<n> t =
   node.traverse(<node> n)

This is a Lua iterator that loops over the node list that starts at n. Typically code looks like this:

```lua
for n in node.traverse(head) do
   ...
end
```

is functionally equivalent to:

```lua
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.

7.2.1.26 node.traverse_id

<node> t =
    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
7.2.1.27 node.traverse_char

This iterator loops over the glyph nodes in a list. Only nodes with a subtype less than 256 are seen.

```
<node> n =
    node.traverse_char(<node> n)
```

7.2.1.28 node.has_glyph

This function returns the first glyph or disc node in the given list:

```
<node> n =
    node.has_glyph(<node> n)
```

7.2.1.29 node.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 endnode this helper return that node, else it follows the list and return the next math endnote. If no such node is found nil is returned.

7.2.1.30 node.remove

```
<node> head, current =
    node.remove(<node> head, <node> current)
```

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.

7.2.1.31 node.insert_before

```
<node> head, new =
    node.insert_before(<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.

7.2.1.32 node.insert_after

```
<node> head, new =
```


node.insert_after(<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.

7.2.1.33 node.first_glyph

<node> n =
    node.first_glyph(<node> n)
<node> n =
    node.first_glyph(<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.

7.2.1.34 node.ligaturing

<node> h, <node> t, <boolean> success =
    node.ligaturing(<node> n)
<node> h, <node> t, <boolean> success =
    node.ligaturing(<node> n, <node> m)

Apply TeX-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).

7.2.1.35 node.kerning

<node> h, <node> t, <boolean> success =
    node.kerning(<node> n)
<node> h, <node> t, <boolean> success =
    node.kerning(<node> n, <node> m)

Apply TeX-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).

7.2.1.36 node.unprotect_glyphs

node.unprotect_glyphs(<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.
7.2.1.37 node.protect_glyphs and node.protect_glyph

node.protect_glyphs(<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.

7.2.1.38 node.last_node

<nodel n =
    node.last_node()

This function pops the last node from \TeX’s ‘current list’. It returns that node, or nil if the current list is empty.

7.2.1.39 node.write

node.write(<node> n)

This is an experimental function that will append a node list to \TeX’s ‘current list’ The node list is not deep-copied! There is no error checking either!

7.2.1.40 node.protrusion_skippable

<boolean> skippable =
    node.protrusion_skippable(<node> n)

Returns true if, for the purpose of line boundary discovery when character protrusion is active, this node can be skipped.

7.2.2 Glue handling

7.2.2.1 node.setglue

You can set the properties of a glue in one go. If you pass no values, the glue will become a zero glue.

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.
7.2.2.2 node.getglue

The next call will return 5 values (or nothing when no glue is passed).

\[
\text{<integer> width, <integer> stretch, <integer> shrink, <integer> stretch_order,}
\text{ <integer> shrink_order} = \text{node.getglue(<node> n)}
\]

When the second argument is false, only the width is returned (this is consistent with tex.get).

7.2.2.3 node.is_zero_glue

This function returns true when the width, stretch and shrink properties are zero.

\[
\text{<boolean> isglue} = \text{node.is_zero_glue(<node> n)}
\]

7.2.3 Attribute handling

Attributes appear as linked list of userdata objects in the attr field of individual nodes. They can be handled individually, but it is much safer and more efficient to use the dedicated functions associated with them.

7.2.3.1 node.has_attribute

\[
\text{<number> v} = 
\text{node.has_attribute(<node> n, <number> id)}
\]
\[
\text{<number> v} = 
\text{node.has_attribute(<node> n, <number> id, <number> val)}
\]

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.

7.2.3.2 node.get_attribute

\[
\text{<number> v} = 
\text{node.get_attribute(<node> n, <number> id)}
\]

Tests if a node has an attribute with number id set. It returns the value, or, if no match is found, nil.

7.2.3.3 node.find_attribute

\[
\text{<number> v, <node> n} = 
\text{node.find_attribute(<node> n, <number> id)}
\]

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.
7.2.3.4 node.set_attribute

node.set_attribute(<node> n, <number> id, <number> val)

Sets the attribute with number id to the value val. Duplicate assignments are ignored. [needs explanation]

7.2.3.5 node.unset_attribute

<number> v =
    node.unset_attribute(<node> n, <number> id)
<number> v =
    node.unset_attribute(<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.

7.2.3.6 node.slide

This helper makes sure that the node lists is double linked and returns the found tail node.

<number> tail =
    node.slide(<node> n)

7.2.3.7 node.check_discretionary and node.check_discretionaries

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 troubles when the linebreak routine kicks in. You can call this function to check the list for issues with disc nodes.

node.check_discretionary(<node> n)
node.check_discretionaries(<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).

7.2.3.8 node.family_font

When you pass it a proper family identifier the next helper will return the font currently associated with it. You can normally also access the font with the normal font field or getter because it will resolve the family automatically for noads.

<integer> id =
    node.family_font(<integer> fam)
7.3 Two access models

Deep down in \TeX a node has a number which is an 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 gets reported when you print node related information.

There are two access models, a robust one using a so called user data object that provides a virtual interface to the internal nodes, and a more direct access which uses the node numbers directly. The first model provide key based access while the second always accesses fields via functions:

```lua
nodeobject.char
getfield(nodonumber,"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 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 an real issue. For that reason we 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 we’re accessing nodes 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:

```lua
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 Lua\TeX 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).

```lua
local next = node.next(current)
if next then
```

128 Nodes
Some accessors are used frequently and for these we provide more efficient helpers:

- **getnext**: parsing nodelist always involves this one
- **getprev**: used less but is logical companion to getnext
- **getboth**: returns the next and prev pointer of a node
- **getid**: consulted a lot
- **getsubtype**: consulted less but also a topper
- **getfont**: used a lot in OpenType handling (glyph nodes are consulted a lot)
- **getchar**: idem and also in other places
- **getwhd**: returns the width, height and depth of a list, rule or (unexpanded) glyph as well as glue (its spec is looked at) and unset nodes
- **getdisc**: returns the pre, post and replace fields and optionally when true is passed also the tail fields.
- **getlist**: we often parse nested lists so this is a convenient one too
- **getleader**: comparable to list, seldom used in TeX (but needs frequent consulting like lists; leaders could have been made a dedicated node type)
- **getfield**: generic getter, sufficient for the rest (other field names are often shared so a specific getter makes no sense then)
- **getbox**: gets the given box (a list node)

In the direct namespace there are more such 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 identify 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.

The setdisc helper takes three (optional) arguments plus an optional fourth indicating the subtype. 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 accessor using getfield and setfield with little overhead.

<table>
<thead>
<tr>
<th>function</th>
<th>node</th>
<th>direct</th>
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<tbody>
<tr>
<td>check_discretionaries</td>
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<td>copy_list</td>
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<td>current_attr</td>
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4 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.
dimensions + +
effective_glue + +
end_of_math + +
family_font + −
fields + −
find_attribute + +
first_glyph + +
flush_list + +
flush_node + +
free + +
get_attribute + +
getattributelist − +
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getid + +
getkern − +
getlang − +
getleader + +
getlist + +
getnext + +
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getoffsets − +
getpenalty − +
getprev + +
getproperty + +
getshift − +
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getsup − +
has_attribute + +
has_field + +
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id + −
insert_after + +
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</tr>
<tr>
<td>setshift</td>
<td></td>
<td></td>
</tr>
<tr>
<td>setwidth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>setwhd</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 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.
8 LUATEX LUA callbacks

8.1 Registering callbacks

This library has functions that register, find and list callbacks. Callbacks are Lua functions that are called in well defined places. There are two kind of callbacks: those that mix with existing functionality, and those that (when enabled) replace functionality. In most 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:

```lua
id, error =
    callback.register (<string> callback_name, <function> func)
```

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. In the latter case, `error` contains an error message, otherwise it is `nil`.

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!

```lua
<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).

```lua
<function> f = callback.find (callback_name)
```

If the callback is not set, `callback.find` returns `nil`.

8.2 File discovery callbacks

The behaviour documented in this subsection is considered stable in the sense that there will not be backward-incompatible changes any more.
8.2.1 find_read_file and find_write_file

Your callback function should have the following conventions:

```
<string> actual_name =
    function (<number> id_number, <string> asked_name)
```

Arguments:

- **id_number**
  This number is zero for the log or \input files. For \TeX's \read or \write the number is incremented by one, so \read0 becomes 1.

- **asked_name**
  This is the user-supplied filename, as found by \input, \openin or \openout.

Return value:

- **actual_name**
  This is the filename used. For the very first file that is read in by \TeX, you have to make sure you return an actual_name that has an extension and that is suitable for use as jobname. If you don’t, you will have to manually fix the name of the log file and output file after Lua\TeX\X is finished, and an eventual format filename will become mangled. That is because these file names depend on the jobname.
  You have to return nil if the file cannot be found.

8.2.2 find_font_file

Your callback function should have the following conventions:

```
<string> actual_name =
    function (<string> asked_name)
```

The asked_name is an otf or tfm font metrics file.
Return nil if the file cannot be found.

8.2.3 find_output_file

Your callback function should have the following conventions:

```
<string> actual_name =
    function (<string> asked_name)
```

The asked_name is the pdf or dvi file for writing.

8.2.4 find_format_file

Your callback function should have the following conventions:

```
<string> actual_name =
```
function (<string> asked_name)

The asked_name is a format file for reading (the format file for writing is always opened in the current directory).

8.2.5 find_vf_file

Like find_font_file, but for virtual fonts. This applies to both Aleph’s ovf files and traditional Knuthian vf files.

8.2.6 find_map_file

Like find_font_file, but for map files.

8.2.7 find_enc_file

Like find_font_file, but for enc files.

8.2.8 find_sfd_file

Like find_font_file, but for subfont definition files.

8.2.9 find_pk_file

Like find_font_file, but for pk bitmap files. This callback takes two arguments: name and dpi. In your callback you can decide to look for:

<base res>dpi/<fontname>.<actual res>pk

but other strategies are possible. It is up to you to find a ‘reasonable’ bitmap file to go with that specification.

8.2.10 find_data_file

Like find_font_file, but for embedded files (\pdfobj file '...').

8.2.11 find_opentype_file

Like find_font_file, but for OpenType font files.

8.2.12 find_truetype_file and find_type1_file

Your callback function should have the following conventions:

<string> actual_name =
function (<string> asked_name)

The asked_name is a font file. This callback is called while Lua\TeX{} is building its internal list of needed font files, so the actual timing may surprise you. Your return value is later fed back into the matching read_file callback.

Strangely enough, find_type1_file is also used for OpenType (otf) fonts.

**8.2.13 find_image_file**

Your callback function should have the following conventions:

<string> actual_name =

function (<string> asked_name)

The asked_name is an image file. Your return value is used to open a file from the hard disk, so make sure you return something that is considered the name of a valid file by your operating system.

**8.2.14 File reading callbacks**

The behavior documented in this subsection is considered stable in the sense that there will not be backward-incompatible changes any more.

**8.2.15 open_read_file**

Your callback function should have the following conventions:

<table> env =

function (<string> file_name)

Argument:

file_name

The filename returned by a previous find_read_file or the return value of kpse.find_file() if there was no such callback defined.

Return value:

env

This is a table containing at least one required and one optional callback function for this file. The required field is reader and the associated function will be called once for each new line to be read, the optional one is close that will be called once when Lua\TeX{} is done with the file.

Lua\TeX{} 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.

**8.2.15.1 reader**

Lua\TeX{} will run this function whenever it needs a new input line from the file.
function(<table> env)
    return <string> line
end

Your function should return either a string or nil. The value nil signals that the end of file has occurred, and will make \TeX{} call the optional close function next.

## 8.2.15.2 close

Lua\TeX{} will run this optional function when it decides to close the file.

```lua
function(<table> env)
end
```

Your function should not return any value.

## 8.2.16 General file readers

There is a set of callbacks for the loading of binary data files. These all use the same interface:

```lua
function(<string> name)
    return <boolean> success, <string> data, <number> data_size
end
```

The `name` will normally be a full path name as it is returned by either one of the file discovery callbacks or the internal version of `kpse.find_file()`.

- **success**
  - Return false when a fatal error occurred (e.g. when the file cannot be found, after all).
- **data**
  - The bytes comprising the file.
- **data_size**
  - The length of the data, in bytes.

Return an empty string and zero if the file was found but there was a reading problem.

The list of functions is as follows:

- `read_font_file`: ofm or tfm files
- `read_vf_file`: virtual fonts
- `read_map_file`: map files
- `read_enc_file`: encoding files
- `read_sfd_file`: subfont definition files
- `read_pk_file`: pk bitmap files
- `read_data_file`: embedded files (as is possible with pdf objects)
- `read_truetype_file`: TrueType font files
- `read_type1_file`: Type1 font files
- `read_opentype_file`: OpenType font files
8.3 Data processing callbacks

8.3.1 process_input_buffer

This callback allows you to change the contents of the line input buffer just before Lua\TeX \textbf{actually} starts looking at it.

```lua
function(<string> buffer)
    return <string> adjusted_buffer
end
```

If you return `nil`, Lua\TeX will pretend like your callback never happened. You can gain a small amount of processing time from that. This callback does not replace any internal code.

8.3.2 process_output_buffer

This callback allows you to change the contents of the line output buffer just before Lua\TeX \textbf{actually} starts writing it to a file as the result of a `\write` command. It is only called for output to an actual file (that is, excluding the log, the terminal, and `\write18` calls).

```lua
function(<string> buffer)
    return <string> adjusted_buffer
end
```

If you return `nil`, Lua\TeX will pretend like your callback never happened. You can gain a small amount of processing time from that. This callback does not replace any internal code.

8.3.3 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.

```lua
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`, Lua\TeX will pretend your callback never happened. This callback does not replace any internal code.

8.4 Node list processing callbacks

The description of nodes and node lists is in chapter 7.

8.4.1 contribute_filter

This callback is called when Lua\TeX 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.

<table>
<thead>
<tr>
<th>value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pre_box</td>
<td>interline material is being added</td>
</tr>
<tr>
<td>pre_adjust</td>
<td>\vadjust material is being added</td>
</tr>
<tr>
<td>box</td>
<td>a typeset box is being added (always called)</td>
</tr>
<tr>
<td>adjust</td>
<td>\vadjust material is being added</td>
</tr>
</tbody>
</table>

### 8.4.2 buildpage_filter

This callback is called whenever Lua\TeX{} 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:

<table>
<thead>
<tr>
<th>value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>alignment</td>
<td>a (partial) alignment is being added</td>
</tr>
<tr>
<td>after_output</td>
<td>an output routine has just finished</td>
</tr>
<tr>
<td>new_graf</td>
<td>the beginning of a new paragraph</td>
</tr>
<tr>
<td>vmode_par</td>
<td>\par was found in vertical mode</td>
</tr>
<tr>
<td>hmode_par</td>
<td>\par was found in horizontal mode</td>
</tr>
<tr>
<td>insert</td>
<td>an insert is added</td>
</tr>
<tr>
<td>penalty</td>
<td>a penalty (in vertical mode)</td>
</tr>
<tr>
<td>before_display</td>
<td>immediately before a display starts</td>
</tr>
<tr>
<td>after_display</td>
<td>a display is finished</td>
</tr>
<tr>
<td>end</td>
<td>Lua\TeX{} is terminating (it’s all over)</td>
</tr>
</tbody>
</table>

### 8.4.3 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.

### 8.4.4 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.

```lua
function(<node> head, <string> groupcode)
    return true | false | <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.

<table>
<thead>
<tr>
<th>value</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;empty&gt;</td>
<td>main vertical list</td>
</tr>
<tr>
<td>hbox</td>
<td>\hbox in horizontal mode</td>
</tr>
<tr>
<td>adjusted hbox</td>
<td>\hbox in vertical mode</td>
</tr>
<tr>
<td>vbox</td>
<td>\vbox</td>
</tr>
<tr>
<td>vtop</td>
<td>\vtop</td>
</tr>
<tr>
<td>align</td>
<td>\halign or \valign</td>
</tr>
<tr>
<td>disc</td>
<td>discretionaries</td>
</tr>
<tr>
<td>insert</td>
<td>packaging an insert</td>
</tr>
<tr>
<td>vcenter</td>
<td>\vcenter</td>
</tr>
<tr>
<td>local_box</td>
<td>\localleftbox or \localrightbox</td>
</tr>
<tr>
<td>split_off</td>
<td>top of a \vsplit</td>
</tr>
<tr>
<td>split_keep</td>
<td>remainder of a \vsplit</td>
</tr>
<tr>
<td>align_set</td>
<td>alignment cell</td>
</tr>
<tr>
<td>fin_row</td>
<td>alignment row</td>
</tr>
</tbody>
</table>

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.

### 8.4.5 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>, Lua\TeX{} will apply the internal linebreak algorithm on the list that starts at \texttt{<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 a hbox. Failure to do so will result in a fatal error.

Setting this callback to \texttt{false} is possible, but dangerous, because it is possible you will end up in an unfixable ‘deadcycles loop’.

### 8.4.6 append\_to\_vlist\_filter

This callback is called whenever Lua\TeX{} adds a box to a vertical list:

function(<node> box, <string> locationcode, <number prevdepth>,
    <boolean> mirrored)
    return list, prevdepth
end

It is ok to return nothing 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.

### 8.4.7 post\_linebreak\_filter

This callback is called just after Lua\TeX{} has converted a list of nodes into a stack of \texttt{\hbox}es.

function(<node> head, <string> groupcode)
    return true | false | <node> newhead
end

This callback does not replace any internal code.

### 8.4.8 hpack\_filter

This callback is called when \TeX{} 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 [], <string> direction] [, <node> attributelist])
    return true | false | <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.

The direction is either one of the three-letter direction specifier strings, or nil.

This callback does not replace any internal code.

**8.4.9 vpack_filter**

This callback is called when \TeX 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 \TeX's \maxdepth setting.

```lua
function(node head, string groupcode, number size, string packtype, number maxdepth [, string direction] [, node attributelist])
    return true | false | node newhead
end
```

This callback does not replace any internal code.

**8.4.10 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:

```lua
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).

**8.4.11 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:

```lua
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.
8.4.12 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.

8.4.13 pre_output_filter
This callback is called when \TeX is ready to start boxing the box 255 for \output.

```lua
function(<node> head, <string> groupcode, <number> size, <string> packtype, <number> maxdepth [, <string> direction])
    return true | false | <node> newhead
end
```

This callback does not replace any internal code.

8.4.14 hyphenate

```lua
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.

8.4.15 ligaturering

```lua
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 Lua\TeX into panic mode.

8.4.16 kerning

```lua
function(<node> head, <node> tail)
end
```
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 Lua\TeX{} into panic mode.

**8.4.17 insert\_local\_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:

```lua
function(<node> local_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.

**8.4.18 mlist\_to\_hlist**

This callback replaces Lua\TeX{}’s math list to node list conversion algorithm.

```lua
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.

**8.5 Information reporting callbacks**

**8.5.1 pre\_dump**

```lua
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.

**8.5.2 start\_run**

```lua
function()
```
This callback replaces the code that prints \LaTeX{}’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.

8.5.3 stop_run

function()
end

This callback replaces the code that prints \LaTeX{}’s statistics and ‘output written to’ messages.

8.5.4 start_page_number

function()
end

Replaces the code that prints the \[ and the page number at the begin of \texttt{\textbackslash shipout}. This callback will also override the printing of box information that normally takes place when \texttt{\textbackslash tracingoutput} is positive.

8.5.5 stop_page_number

function()
end

Replaces the code that prints the \] at the end of \texttt{\textbackslash shipout}.

8.5.6 show_error_hook

function()
end

This callback is run from inside the \TeX{} error function, and the idea is to allow you to do some extra reporting on top of what \TeX{} already does (none of the normal actions are removed). You may find some of the values in the status table useful. This callback does not replace any internal code.

8.5.7 show_error_message

function()
end

This callback replaces the code that prints the error message. The usual interaction after the message is not affected.
8.5.8 show_lua_error_hook

function()
end

This callback replaces the code that prints the extra Lua error message.

8.5.9 start_file

function(category, filename)
end

This callback replaces the code that prints LuaTeX’s when a file is opened like (filename for regular files. The category is a number:

1  a normal data file, like a \TeX 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

8.5.10 stop_file

function(category)
end

This callback replaces the code that prints LuaTeX’s when a file is closed like the ) for regular files.

8.5.11 call_edit

function(filename, linenumber)
end

This callback replaces the call to an external editor when ‘E’ is pressed in reply to an error message. Processing will end immediately after the callback returns control to the main program.

8.6 PDF-related callbacks

8.6.1 finish_pdffile

function()
end
This callback is called when all document pages are already written to the pdf file and LuaTEx is about to finalize the output document structure. Its intended use is final update of pdf dictionaries such as /Catalog or /Info. The callback does not replace any code. There are neither arguments nor return values.

### 8.6.2 finish_pdfpage

```lua
function(shippingout)
end
```

This callback is called after the pdf page stream has been assembled and before the page object gets finalized.

### 8.7 Font-related callbacks

#### 8.7.1 define_font

```lua
function(<string> name, <number> size, <number> id)
    return <table> font | <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 designsize of the font.

The id is the internal number assigned to the font.

The internal structure of the font table that is to be returned is explained in chapter 5. 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.
9 The \TeX\ related libraries

9.1 The lua library

9.1.1 LUA version

This library contains one read-only item:

```latex
<string> s = lua.version
```

This returns the Lua version identifier string. The value is currently Lua 5.2.

9.1.2 LUA bytecode registers

Lua registers can be used to communicate Lua functions across Lua chunks. The accepted values for assignments are functions and \texttt{nil}. Likewise, the retrieved value is either a function or \texttt{nil}.

```latex
lua.bytecode[<number> n] = <function> f
lua.bytecode[<number> n]()
```

The contents of the \texttt{lua.bytecode} array is stored inside the format file as actual Lua bytecode, so it can also be used to preload Lua code.

Note: The function must not contain any upvalues. Currently, functions containing upvalues can be stored (and their upvalues are set to \texttt{nil}), but this is an artifact of the current Lua implementation and thus subject to change.

The associated function calls are

```latex
<function> f = lua.getbytecode(<number> n)
lua.setbytecode(<number> n, <function> f)
```

Note: Since a Lua file loaded using \texttt{loadfile(filename)} is essentially an anonymous function, a complete file can be stored in a bytecode register like this:

```latex
lua.bytecode[n] = loadfile(filename)
```

Now all definitions (functions, variables) contained in the file can be created by executing this bytecode register:

```latex
lua.bytecode[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 \texttt{ini\TeX}. 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 \texttt{ini\TeX}. 
9.1.3 LUA chunk name registers

There is an array of 65536 (0-65535) potential chunk names for use with the `\directlua` and `\latelua` primitives.

lua.name[<number> n] = <string> s
<string> s = lua.name[<number> n]

If you want to unset a Lua name, you can assign `nil` to it.

9.2 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()
</table>

The keys in the table are the known items, the value is the current value. Almost all of the values in `status` are fetched through a metatable at run-time whenever they are accessed, so you cannot use `pairs` on `status`, but you can use `pairs` on `info`, of course. If you do not need the full list, you can also ask for a single item by using its name as an index into `status`.

The current list is:

<table>
<thead>
<tr>
<th>key</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>banner</td>
<td>terminal display banner</td>
</tr>
<tr>
<td>best_page_break</td>
<td>the current best break (a node)</td>
</tr>
<tr>
<td>buf_size</td>
<td>current allocated size of the line buffer</td>
</tr>
<tr>
<td>callbacks</td>
<td>total number of executed callbacks so far</td>
</tr>
<tr>
<td>cs_count</td>
<td>number of control sequences</td>
</tr>
<tr>
<td>dest_names_size</td>
<td>pdf destination table size</td>
</tr>
<tr>
<td>dvi_gone</td>
<td>written dvi bytes</td>
</tr>
<tr>
<td>dvi_ptr</td>
<td>not yet written dvi bytes</td>
</tr>
<tr>
<td>dyn_used</td>
<td>token (multi-word) memory in use</td>
</tr>
<tr>
<td>filename</td>
<td>name of the current input file</td>
</tr>
<tr>
<td>fix_mem_end</td>
<td>maximum number of used tokens</td>
</tr>
<tr>
<td>fix_mem_min</td>
<td>minimum number of allocated words for tokens</td>
</tr>
<tr>
<td>fix_mem_max</td>
<td>maximum number of allocated words for tokens</td>
</tr>
<tr>
<td>font_ptr</td>
<td>number of active fonts</td>
</tr>
<tr>
<td>hash_extra</td>
<td>extra allowed hash</td>
</tr>
<tr>
<td>hash_size</td>
<td>size of hash</td>
</tr>
<tr>
<td>indirect_callbacks</td>
<td>number of those that were themselves a result of other callbacks (e.g. file readers)</td>
</tr>
<tr>
<td>ini_version</td>
<td><code>true</code> if this is an \initex run</td>
</tr>
<tr>
<td>init_pool_ptr</td>
<td>\initex string pool index</td>
</tr>
<tr>
<td>init_str_ptr</td>
<td>number of \initex strings</td>
</tr>
</tbody>
</table>
input_ptr
inputid
largest_used_mark
lasterrorcontext
lasterrorstring
lastluaerrorstring
lastwarningstring
lastwarningtag
linenumber
log_name
luabytecode_bytes
luabytecodes
luastate_bytes
luatex_engine
luatex_hashchars
luatex_hashtype
luatex_revision
luatex_revision
luatex_version
max_buf_stack
max_in_stack
max_nest_stack
max_param_stack
max_save_stack
max_strings
nest_size
node_mem_usage
obj_ptr
obj_tab_size
output_active
output_file_name
param_size
pdf_dest_names_ptr
pdf_gone
pdf_mem_ptr
pdf_mem_size
pdf_os_cntr
pdf_os_objidx
pdf_ptr
pool_ptr
pool_size
save_size
shell_escape
stack_size
str_ptr
total_pages

th e level of input we’re at
numeric id of the current input
max referenced marks class
last error context string (with newlines)
last \TeX error string
last Lua error string
last warning string, normally an indication of in what part
last warning string
location in the current input file
name of the log file
number of bytes in Lua bytecode registers
number of active Lua bytecode registers
number of bytes in use by Lua interpreters
the Lua\TeX engine identifier
length to which Lua hashes strings ($2^n$)
the hash method used (in Luajit\TeX)
the Lua\TeX revision string
the Lua\TeX revision string
the Lua\TeX version number
max used buffer position
max used input stack entries
max used nesting stack entries
max used parameter stack entries
max used save stack entries
maximum allowed strings
nesting stack size
a string giving insight into currently used nodes
max pdf object pointer
pdf object table size
true if the \texttt{output} routine is active
name of the pdf or dvi file
parameter stack size
max pdf destination pointer
written pdf bytes
max pdf memory used
pdf memory size
max pdf object stream pointer
pdf object stream index
not yet written pdf bytes
string pool index
current size allocated for string characters
save stack size
0 means disabled, 1 is restricted and 2 means anything is permitted
input stack size
number of strings
number of written pages
The error and warning messages can be wiped with the \resetmessages function.

### 9.3 The \texttt{tex} library

The \texttt{tex} table contains a large list of virtual internal \TeX\ 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 \TeX\ values. As a result, most of the Lua table operators (like \texttt{pairs} and \texttt{#}) do not work on such items. At the moment, it is possible to access almost every parameter that has these characteristics:

- You can use it after \texttt{\the}\n
- It is a single token.
- Some special others, see the list below

This excludes parameters that need extra arguments, like \texttt{\the\scriptfont}.

The subset comprising simple integer and dimension registers are writable as well as readable (stuff like \texttt{\tracingcommands} and \texttt{\parindent}).

#### 9.3.1 Internal parameter values

For all the parameters in this section, it is possible to access them directly using their names as index in the \texttt{tex} table, or by using one of the functions \texttt{tex.get} and \texttt{tex.set}.

The exact parameters and return values differ depending on the actual parameter, and so does whether \texttt{tex.set} has any effect. For the parameters that \texttt{can} be set, it is possible to use \texttt{global} as the first argument to \texttt{tex.set}; this makes the assignment global instead of local.

\begin{verbatim}
\texttt{tex.set ("["global",]\texttt{]} \texttt{<string>}\ n, ...}  
\texttt{... = tex.get (\texttt{<string>}\ n)}
\end{verbatim}

Glue is kind of special because there are five values involved. The return value is a \texttt{glue\_spec} node but when you pass \texttt{false} as last argument to \texttt{tex.get} you get the width of the glue and when you pass \texttt{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 \texttt{glue\_spec} or upto five numbers.

For the registers you can use \texttt{getskip (node)}, \texttt{getglue (numbers)} \texttt{setskip (node)} and \texttt{setglue (numbers)}.

There are also dedicated setters, getters and checkers:

\begin{verbatim}
local \ d = tex.getdimen("foo")
if tex.isdimen("bar") then
  tex.setdimen("bar",\ d)
end
\end{verbatim}
There are such helpers for dimen, count, skip, box and attribute registers.

### 9.3.1.1 Integer parameters

The integer parameters accept and return Lua numbers.

Read-write:

- \texttt{tex_adjdemerits}
- \texttt{tex_binoppenalty}
- \texttt{tex_brokenpenalty}
- \texttt{tex_catcodetable}
- \texttt{tex_clubpenalty}
- \texttt{tex_day}
- \texttt{tex_defaulthyphenchar}
- \texttt{tex_defultskewchar}
- \texttt{tex_delimiterfactor}
- \texttt{tex_displaywidowpenalty}
- \texttt{tex_doublehyphendemerits}
- \texttt{tex_endlinechar}
- \texttt{tex_errorcontextlines}
- \texttt{tex_escapechar}
- \texttt{tex_exhyphenpenalty}
- \texttt{tex_fam}
- \texttt{tex_finalhyphendemerits}
- \texttt{tex_floatingpenalty}
- \texttt{tex_globaldefs}
- \texttt{tex_hangafter}
- \texttt{tex_hbadness}
- \texttt{tex_holdinginserts}
- \texttt{tex_hyphenpenalty}
- \texttt{tex_interlinepenalty}
- \texttt{tex_language}
- \texttt{tex_lastlinefit}
- \texttt{tex_lefthyphenmin}
- \texttt{tex_linepenalty}
- \texttt{tex_localbrokenpenalty}
- \texttt{tex_localinterlinepenalty}
- \texttt{tex_looseness}
- \texttt{tex_mag}
- \texttt{tex_maxdeadcycles}
- \texttt{tex_month}

Read-only:

- \texttt{tex_deadcycles}
- \texttt{tex_insertpenalties}
- \texttt{tex_parshape}
- \texttt{tex_prevgraf}
- \texttt{tex_spacefactor}

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9.3.1.2 Dimension parameters

The dimension parameters accept Lua numbers (signifying scaled points) or strings (with included dimension). The result is always a number in scaled points.

Read-write:

- tex.boxmaxdepth
- tex.delimitershortfall
- tex.displayindent
- tex.displaywidth
- tex.emergencystretch
- tex.hangindent
- tex.hfuzz
- tex.hoffset
- tex.hsize
- tex.lineskiplimit
- tex.boxmaxdepth
- tex.mathsurround
- tex.parindent
- tex.maxdepth
- tex.nulldelimiterspace
- tex.overfullrule
- tex.splitmaxdepth
- tex.pagebottomoffset
- tex.pageheight
- tex.vfuzz
- tex.hoffset
- tex.hsize
- tex.pagefillstretch
- tex.pagefilstretch
- tex.pagewidth
- tex.pagemargin
- tex.pagegoal
- tex.pageshrink
- tex.pagefillstretch
- tex.pagemargin
- tex.pageshrink
- tex.prevdepth
- tex.prevgraf
- tex.spacefactor

Read-only:

- tex.pagedepth
- tex.pagefillstretch
- tex.pagefilstretch
- tex.pagefillstretch
- tex.pagefillstretch
- tex.pagefillstretch
- tex.pagefillstretch
- tex.pagefillstretch
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9.3.1.4 Glue parameters

The glue parameters accept and return a userdata object that represents a glue_spec node.

- tex.abovedisplayshortskip
- tex.abovedisplayskip
- tex.baselineskip
- tex.belowdisplayshortskip
- tex.belowdisplayskip
- tex.leftskip
- tex.lineskip
- tex.parfillskip
- tex.parskip
- tex.rightskip
- tex.spaceskip
- tex.splittopskip
- tex.tabskip
- tex.topskip
- tex.xspaceskip

9.3.1.5 Muglue parameters

All muglue parameters are to be used read-only and return a Lua string.

- tex.medmuskip
- tex.thickmuskip
- tex.thinmuskip

9.3.1.6 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.

- tex.errhelp
- tex.everycr
- tex.everydisplay
- tex.everyeof
- tex.everyhbox
- tex.everyjob
- tex.everymath
- tex.everypar
- tex.everyvbox
- tex.output
- tex.toks

9.3.2 Convert commands

All ‘convert’ commands are read-only and return a Lua string. The supported commands at this moment are:

- tex.eTeXVersion
- tex.eTeXrevision
- tex.formatname
- tex.jobname
- tex.luatexbanner
- tex.luatexrevision
- tex.fontname(number)
- tex.uniformdeviate(number)
- tex.number(number)
- tex.romannumeral(number)
- tex.fontidentifier(number)

If you are wondering why this list looks haphazard; these are all the cases of the ‘convert’ internal command that do not require an argument, as well as the ones that require only a simple numeric
The special (lua-only) case of \textfontidentifier returns the \textcsname string that matches a font id number (if there is one).

if these are really needed in a macro package.

### 9.3.3 Last item commands

All ‘last item’ commands are read-only and return a number.

The supported commands at this moment are:

- tex.lastpenalty
- tex.lastkern
- tex.lastskip
- tex.lastnodetype
- tex.inputlineno
- tex.lastxpos
- tex.lastypos
- tex.randomseed
- tex.luatexversion
- tex.eTExminorversion
- tex.eTExversion
- tex.currentgrouplevel
- tex.currentgrouptype
- tex.currentiflevel
- tex.currentiftype
- tex.currentifbranch

### 9.3.4 Attribute, count, dimension, skip and token registers

\TeX’s attributes (\textattribute), counters (\textcount), dimensions (\texdimen), skips (\textskip) and token (\texttoks) registers can be accessed and written to using two times five virtual sub-tables of the \text table:

- \texattribute
- \textdimen
- \texttoks
- \textskip

It is possible to use the names of relevant \textattributedef, \textcountdef, \textdimendef, \textskipdef, or \texttoksdef control sequences as indices to these tables:

- \textcount.scratchcounter = 0
- \textdimen.maxdimen = tex.dimen['maxdimen']

In this case, Lua\TeX looks up the value for you on the fly. You have to use a valid \textcountdef (or \textattributedef, or \textdimendef, or \textskipdef, or \texttoksdef), anything else will generate an error (the intent is to eventually also allow <chardef tokens> and even macros that expand into a number).

The attribute and count registers accept and return Lua numbers.

The dimension registers accept Lua numbers (in scaled points) or strings (with an included absolute dimension; \textem and \textex and \textpx 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 \textthe\texttoks style expansion: all category codes are either space (10) or other (12).

The skip registers accept and return \textgluespec userdata node objects (see the description of the node interface elsewhere in this manual).
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:

\begin{verbatim}
\text{tex.setskip (["global",], <number> n, <node> s)}
\text{tex.setskip (["global",], <string> s, <node> s)}
<node> s = \text{tex.getskip (<number> n)}
<node> s = \text{tex.getskip (<string> s)}
\end{verbatim}

We have similar setters for count, dimen, muskip, and toks. Counters and dimen are represented by numbers, skips and muskips by nodes, and toks by strings. For tokens registers we have an alternative where a catcode table is specified:

\begin{verbatim}
\text{tex.scantoks(0,3,"$e=mc^2$" )}
\text{tex.scantoks("global",0, "$\int\limits^1_2$" )}
\end{verbatim}

In the function-based interface, it is possible to define values globally by using the string global as the first function argument.

There are four extra skip related helpers:

\begin{verbatim}
\text{tex.setglue (["global"], <number> n, width, stretch, shrink, stretch_order, shrink_order)}
\text{tex.setglue (["global"], <string> s, width, stretch, shrink, stretch_order, shrink_order)}
width, stretch, shrink, stretch_order, shrink_order = \text{tex.getglue (<number> n)}
width, stretch, shrink, stretch_order, shrink_order = \text{tex.getglue (<string> s)}
\end{verbatim}

The other two are tex.setmuglue and tex.getmuglue.

\subsection*{9.3.5 Character code registers}

\TeX's character code tables (\lccode, \uccode, \sfcode, \catcode, \mathcode, \delcode) can be accessed and written to using six virtual subtables of the tex table

\begin{verbatim}
\text{tex.lccode} \quad \text{tex.sfcode} \quad \text{tex.mathcode}
\text{tex.uccode} \quad \text{tex.catcode} \quad \text{tex.delcode}
\end{verbatim}

The function call interfaces are roughly as above, but there are a few twists. sfcodes are the simple ones:

\begin{verbatim}
\text{tex.setsfcode (["global",], <number> n, <number> s)}
<number> s = \text{tex.getsfcode (<number> n)}
\end{verbatim}

The function call interface for lccode and uccode additionally allows you to set the associated sibling at the same time:

\begin{verbatim}
\text{tex.setlccode (["global"], <number> n, <number> lc)}
\end{verbatim}
The function call interface for \texttt{catcode} also allows you to specify a category table to use on assignment or on query (default in both cases is the current one):

\begin{verbatim}
<function> lc = tex.getlccode (<number> n)
<function> lc = tex.getlccode (<number> cattable, <number> n)
\end{verbatim}

The interfaces for \texttt{delcode} and \texttt{mathcode} use small array tables to set and retrieve values:

\begin{verbatim}
<function> mval = tex.getmathcode (<number> n)
<function> mval = tex.getmathcode (<number> cattable, <number> n)
<function> mval = tex.getmathcode (<number> n)
<function> mval = tex.getmathcode (<number> cattable, <number> n)
\end{verbatim}

Where the table for \texttt{mathcode} is an array of 3 numbers, like this:

\begin{verbatim}
{  
  <number> class,  
  <number> family,  
  <number> character  
}
\end{verbatim}

And the table for \texttt{delcode} is an array with 4 numbers, like this:

\begin{verbatim}
{  
  <number> small_fam,  
  <number> small_char,  
  <number> large_fam,  
  <number> large_char  
}
\end{verbatim}

You can also avoid the table:

\begin{verbatim}
<function> class, family, char =  
  tex.getmathcodes (<number> n)
<function> smallfam, smallchar, largefam, largechar =  
  tex.getdelcodes (<number> n)
\end{verbatim}
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 $-1$.

### 9.3.6 Box registers

It is possible to set and query actual boxes, using the node interface as defined in the node library:

```latex
\texttt{tex.box}
```

for array access, or

```latex
\texttt{tex.setbox(["global",] <number> n, <node> s)}
\texttt{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

```latex
\texttt{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 \texttt{node.copy_list()} unless you are assigning to a temporary variable:

```latex
\texttt{tex.box[0] = node.copy_list(tex.box[2])}
```

The following function will register a box for reuse (this is modeled after so called xforms in pdf). You can (re)use the box with \useboxresource or by creating a rule node with subtype 2.

```latex
\texttt{local index = tex.saveboxresource(n,attributes,resources,immediate,type)}
```

The optional second and third arguments are strings, the fourth is a boolean. The fifth argument is a type. 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.

You can generate the reference (a rule type) with:

```latex
\texttt{local reused = tex.useboxresource(n,wd,ht,dp)}
```

The dimensions are optional and the final ones are returned as extra values. The following is just a bonus (no dimensions returned means that the resource is unknown):

```latex
\texttt{local w, h, d = tex.getboxresourcedimensions(n)}
```

You can split a box:

```latex
\texttt{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.

9.3.7 Math parameters

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:

- quad
- overbarkern
- underbarkern
- radicalkern
- radicaldegreebefore
- stackvgap
- fractionrule
- fractiondenomomvgap
- limitabovemvgap
- limitbelowmvgap
- underdelimitervgap
- overdelimitervgap
- subshiftdrop
- subsupshiftdown
- subbottommin
- spaceafterscript
- ordordspacing
- opordspacing
- binordspacing
- relordspacing
- relopenspacing
- openordspacing
- closeordspacing
- closeopenspacing
- punctordspacing
- punctopenspacing
- innerordspacing
inneropenspacing innerclosespacing innerpunctspacing innerinnnerspacing

The values for the style parameter name 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.

### 9.3.8 Special list heads

The virtual table \texttt{tex.lists} contains the set of internal registers that keep track of building page lists.

<table>
<thead>
<tr>
<th>field</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>page_ins_head</td>
<td>circular list of pending insertions</td>
</tr>
<tr>
<td>contrib_head</td>
<td>the recent contributions</td>
</tr>
<tr>
<td>page_head</td>
<td>the current page content</td>
</tr>
<tr>
<td>hold_head</td>
<td>used for held-over items for next page</td>
</tr>
<tr>
<td>adjust_head</td>
<td>head of the current \texttt{\vadjust} list</td>
</tr>
<tr>
<td>pre_adjust_head</td>
<td>head of the current \texttt{\vadjust	exttt{pre}} list</td>
</tr>
<tr>
<td>page_discards_head</td>
<td>head of the discarded items of a page break</td>
</tr>
<tr>
<td>split_discards_head</td>
<td>head of the discarded items in a vsplit</td>
</tr>
</tbody>
</table>

### 9.3.9 Semantic nest levels

The virtual table \texttt{tex.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 \texttt{tex.nest.ptr}, which gives the highest available index. Neither the array items in \texttt{tex.nest[]} nor \texttt{tex.nest.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. \texttt{tex.nest[tex.nest.ptr].prevdepth}.

tex.nest[tex.nest.ptr] is the current nest state, tex.nest[0] the outermost (main vertical list) level.

The known fields are:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>modes</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>mode</td>
<td>number</td>
<td>all</td>
<td>a number representing the main mode at this level: 0 = no mode (this happens during \texttt{\write}), 1 = vertical, 127 = horizontal, 253 = display math, -1 = internal vertical, -127 = restricted horizontal, -253 = inline math</td>
</tr>
<tr>
<td>modeline</td>
<td>number</td>
<td>all</td>
<td>source input line where this mode was entered in, negative inside the output routine</td>
</tr>
</tbody>
</table>
9.3.10 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.

9.3.10.1 tex.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.

9.3.10.2 tex.sprint

tex.sprint(<string> s, ...)

head node all the head of the current list
tail node all the tail of the current list
prevgraf number vmode number of lines in the previous paragraph
prevdepth number vmode depth of the previous paragraph
spacefactor number hmode the current space factor
dirs node hmode used for temporary storage by the line break algorithm
noad node mmode used for temporary storage of a pending fraction numerator, for \over etc.
delimptr node mmode used for temporary storage of the previous math delimiter, for \middle
mathdir boolean mmode true when during math processing the \mathdir is not the same as the surrounding \textdir
mathstyle number mmode the current \mathstyle
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 \texttt{\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

\begin{verbatim}
before\directlua{tex.sprint("relax")}tex.sprint(" inbetween")after

the space before in between will be gobbled as a result of the ‘normal’ scanning of relax.
\end{verbatim}

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 \texttt{tex.print()}.

\subsection{tex.tprint}

\texttt{tex.tprint\{\langle number\rangle \ n, \ \langle string\rangle \ s, \ ..., \ \}, \ ...\}}

This function is basically a shortcut for repeated calls to \texttt{tex.sprint\langle number\rangle \ n, \ \langle string\rangle \ s, \ ...\}}, once for each of the supplied argument tables.

\subsection{tex.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.

\begin{verbatim}
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
\end{verbatim}

\subsection{tex.write}

\texttt{tex.write\langle string\rangle \ s, \ ...\}}
\texttt{tex.write\langle table\rangle \ t}

Each string argument is treated by \TeX 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).

### 9.3.11 Helper functions

#### 9.3.11.1 tex.round

\[ n = \text{tex.round}(o) \]

Rounds Lua number \( o \), and returns a number that is in the range of a valid \TeX\ register value. If the number starts out of range, it generates a ‘number to big’ error as well.

#### 9.3.11.2 tex.scale

\[ n = \text{tex.scale}(o, \text{delta}) \]
\[ n = \text{tex.scale}(\text{table} o, \text{delta}) \]

Multiplies the Lua numbers \( o \) and \( \text{delta} \), and returns a rounded number that is in the range of a valid \TeX\ 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 to 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 Lua\TeX\’s internal, 100% portable scale function will be added at a later date.

#### 9.3.11.3 tex.sp

\[ n = \text{tex.sp}(o) \]
\[ n = \text{tex.sp}(s) \]

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 Lua\TeX\ 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 (\text{fil}...) are forbidden
3. \text{mu} units do not generate an error (but may not be useful either)

#### 9.3.11.4 tex.definefont

\[ \text{tex.definefont}(\text{csname}, \text{fontid}) \]
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).

9.3.11.5 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 read 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.

9.3.11.6 tex.error

tex.error(<string> s)
tex.error(<string> s, <table> help)

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.

9.3.11.7 tex.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.

9.3.12 Functions for dealing with primitives

9.3.12.1 tex.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 \TeXX82, or \directlua). If it is not, \texttt{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 \texttt{\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.

An example:

\begin{verbatim}
tex.enableprimitives('Lua\TeX', {'formatname'})
\end{verbatim}

will define \texttt{\LuaTeXformatname} with the same intrinsic meaning as the documented primitive \texttt{\formatname}, provided that the control sequences \texttt{\LuaTeXformatname} is currently undefined.

When \texttt{\LuaTeX} is run with --\texttt{-ini} only the \TeXX82 primitives and \directlua are available, so no extra primitives at all.

If you want to have all the new functionality available using their default names, as it is now, you will have to add

\begin{verbatim}
\ifx\directlua\undefined \else
\directlua {tex.enableprimitives('',tex.extraprimitives ())}
\fi
\end{verbatim}

near the beginning of your format generation file. Or you can choose different prefixes for different subsets, as you see fit.

Calling some form of \texttt{tex.enableprimitives()} is highly important though, because if you do not, you will end up with a \TeXX82-lookalike that can run Lua code but not do much else. The defined csnames are (of course) saved in the format and will be available at runtime.

\section*{9.3.12.2 tex.extraprimitives}
\begin{verbatim}
t = tex.extraprimitives(<string> s, ...)
\end{verbatim}

This function returns a list of the primitives that originate from the engine(s) given by the requested string value(s). The possible values and their (current) return values are:

\begin{verbatim}
name values
tex vskip write vsize \normalcontrolspace boundary unhcopy output - / unskip unvbox boxmaxdepth muskipdef string tokosdef floatingpenalty rigththyphenmin voffset escapechar topmark splitfirstmark vsplit everydisplay badness xleaders textfont showlists language mathchoice topskip topskipabs displayshortskip underlinetracing lostchars pagefillstretch unvcopy splitbotmark finalhyphen\-demerits atopwithdelims pretolerance fi dp setlanguage ht mathchardef nulldef limiterspace or wd pagegoal advance chardef catcode mathchar scriptscriptfont mathcode leftskip pageshrink pagefillstretch delcode fontname brokenpenalty
\end{verbatim}
Notethat\textit{luatex} does not contain \textit{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 \texttt{tex.extraprimitives()} will give you the complete list of primitives -ini startup. It is exactly equivalent to \texttt{tex.extraprimitives("etex","luatex")}.

\section*{9.3.12.3 tex.primitives}

\texttt{<table> t = tex.primitives()}

This function returns a list of all primitives that \textit{Lua\TeX} knows about.

\section*{9.3.13 Core functionality interfaces}

\subsection*{9.3.13.1 tex.badness}

\texttt{<number> b = tex.badness(<number> t, <number> s)}

This helper function is useful during linebreak calculations. \texttt{t} and \texttt{s} are scaled values; the function returns the badness for when total \texttt{t} is supposed to be made from amounts that sum to \texttt{s}. The returned number is a reasonable approximation of $100(t/s)^3$;

\subsection*{9.3.13.2 tex.resetparagraph}

This function resets the parameters that \TeX{} normally resets when a new paragraph is seen.

\subsection*{9.3.13.3 tex.linebreak}

\texttt{local <node> modelist, <table> info =}
tex.linebreak(<node> listhead, <table> parameters)

The understood parameters are as follows:

<table>
<thead>
<tr>
<th>name</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pardir</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>pretolerance</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>tracingparagraphs</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>tolerance</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>looseness</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hyphenpenalty</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>exhyphenpenalty</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>pdfadjustspacing</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>adjdemerits</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>pdfprotrudechars</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>linepenalty</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>lastlinefit</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>doublehyphenpenalties</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>finalhyphenpenalties</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hangafter</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>interlinepenalty</td>
<td>number or table</td>
<td>if a table, then it is an array like \interlinepenalties</td>
</tr>
<tr>
<td>clubpenalty</td>
<td>number or table</td>
<td>if a table, then it is an array like \clubpenalties</td>
</tr>
<tr>
<td>widowpenalty</td>
<td>number or table</td>
<td>if a table, then it is an array like \widowpenalties</td>
</tr>
<tr>
<td>brokenpenalty</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>emergencystretch</td>
<td>number</td>
<td>in scaled points</td>
</tr>
<tr>
<td>hangindent</td>
<td>number</td>
<td>in scaled points</td>
</tr>
<tr>
<td>hsize</td>
<td>number</td>
<td>in scaled points</td>
</tr>
<tr>
<td>leftskip</td>
<td>glue_spec node</td>
<td></td>
</tr>
<tr>
<td>rightskip</td>
<td>glue_spec node</td>
<td></td>
</tr>
<tr>
<td>pdfignoredimen</td>
<td>number</td>
<td>in scaled points</td>
</tr>
<tr>
<td>parshape</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

Note that there is no interface for \displaywidowpenalties, you have to pass the right choice for widowpenalties yourself.

The meaning of the various keys should be fairly obvious from the table (the names match the \TeX primitive and pdf\TeX primitives) except for the last 5 entries. The four pdf...line... keys are ignored if their value equals pdfignoredimen.

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 local_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:

prevdepth depth of the last line in the broken paragraph
prevgraf number of lines in the broken paragraph
looseness the actual looseness value in the broken paragraph
demerits 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.

9.3.13.4 tex.shipout

tex.shipout(<number> n)

Ships out box number n to the output file, and clears the box register.

9.4 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.

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>default</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>kpse_init</td>
<td>boolean</td>
<td>true</td>
<td>false totally disables kpathsea initialisation, and enables interpretation of the following numeric key–value pairs. (only ever unset this if you implement all file find callbacks!)</td>
</tr>
<tr>
<td>shell_escape</td>
<td>string</td>
<td>'f'</td>
<td>Use 'y' or 't' or '1' to enable \write 18 unconditionally, 'p' to enable the commands that are listed in shell_escape_commands</td>
</tr>
<tr>
<td>shell_escape_commands</td>
<td>string</td>
<td></td>
<td>Comma-separated list of command names that may be executed by \write 18 even if shell_escape is set to 'p'. Do not use spaces around commas, separate any required command arguments by using a space, and use the ascii double quote (&quot;) for any needed argument or path quoting</td>
</tr>
<tr>
<td>string_vacancies</td>
<td>number</td>
<td>75000</td>
<td>cf. web2c docs</td>
</tr>
<tr>
<td>pool_free</td>
<td>number</td>
<td>5000</td>
<td>cf. web2c docs</td>
</tr>
<tr>
<td>max_strings</td>
<td>number</td>
<td>15000</td>
<td>cf. web2c docs</td>
</tr>
<tr>
<td>strings_free</td>
<td>number</td>
<td>100</td>
<td>cf. web2c docs</td>
</tr>
<tr>
<td>nest_size</td>
<td>number</td>
<td>50</td>
<td>cf. web2c docs</td>
</tr>
<tr>
<td>max_in_open</td>
<td>number</td>
<td>15</td>
<td>cf. web2c docs</td>
</tr>
</tbody>
</table>
param_size number 60 cf. web2c docs
save_size number 4000 cf. web2c docs
stack_size number 300 cf. web2c docs
dvi_buf_size number 16384 cf. web2c docs
error_line number 79 cf. web2c docs
half_error_line number 50 cf. web2c docs
max_print_line number 79 cf. web2c docs
hash_extra number 0 cf. web2c docs
pk_dpi number 72 cf. web2c docs
trace_file_names boolean true false disables \TeX\’s normal file open-close feedback (the assumption is that callbacks will take care of that)

file_line_error boolean false do file:line style error messages
halt_on_error boolean false abort run on the first encountered error
formatname string if no format name was given on the command line, this key will be tested first instead of simply quitting
jobname string if no input file name was given on the command line, this key will be tested first instead of simply giving up

Note: the numeric values that match web2c parameters are only used if kpse_init is explicitly set to false. In all other cases, the normal values from texmf.cnf are used.

9.5 The texio library

This library takes care of the low-level I/O interface: writing to the log file and/or console.

9.5.1 texio.write

texio.write(<string> target, <string> s, ...)
texio.write(<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 three possibilities: term, log or term and log.

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.

9.5.2 texio.write_nl

texio.write_nl(<string> target, <string> s, ...)
texio.write_nl(<string> s, ...)
This function behaves like `texio.write`, but make 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.

### 9.5.3 texio.setescape

You can disable `^^` escaping of control characters by passing a value of zero.

### 9.6 The token library

#### 9.6.1 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 ok 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 Lua\TeX is to provide a minimal set of tools and no solutions. The functions provided in the token namespace are given in the next table:

<table>
<thead>
<tr>
<th>function</th>
<th>argument</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>is_token</td>
<td>token</td>
<td>checks if the given argument is a token userdatum</td>
</tr>
<tr>
<td>get_next</td>
<td></td>
<td>returns the next token in the input</td>
</tr>
<tr>
<td>scan_keyword</td>
<td>string</td>
<td>returns true if the given keyword is gobbled</td>
</tr>
<tr>
<td>scan_int</td>
<td>string</td>
<td>returns a number</td>
</tr>
<tr>
<td>scan_dimen</td>
<td>infinity, mu-units</td>
<td>returns a number representing a dimension and or two numbers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>being the filler and order</td>
</tr>
<tr>
<td>scan_glue</td>
<td>mu-units</td>
<td>returns a glue spec node</td>
</tr>
<tr>
<td>scan_toks</td>
<td>definer, expand</td>
<td>returns a table of tokens token list (this can become a linked list</td>
</tr>
<tr>
<td></td>
<td></td>
<td>in later releases)</td>
</tr>
<tr>
<td>scan_code</td>
<td>bitset</td>
<td>returns a character if its category is in the given bitset (representing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>catcodes)</td>
</tr>
<tr>
<td>scan_string</td>
<td></td>
<td>returns a string given between <code>{}</code>, as \macro or as sequence of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>characters with catcode 11 or 12 as string</td>
</tr>
<tr>
<td>scan_word</td>
<td></td>
<td>returns a sequence of characters with catcode 11 or 12 as string</td>
</tr>
<tr>
<td>scan_csname</td>
<td></td>
<td>returns foo after scanning \foo</td>
</tr>
<tr>
<td>set_macro</td>
<td>see below</td>
<td>assign a macro</td>
</tr>
<tr>
<td>create</td>
<td></td>
<td>returns a userdata token object of the given control sequence name</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(or character); this interface can change</td>
</tr>
</tbody>
</table>

The scanners can be considered stable apart from the one scanning for a token. This is because futures releases can return a linked list instead of a table (as with nodes). The `scan_code` function takes an optional number, the `keyword` 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 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\bar{bar}
\def\foo{foo-\bar}

we get:

\directlua{token.scan_string()}{foo} foo full expansion
\directlua{token.scan_string()}{foo} foo letters and others
\directlua{token.scan_string()}{foo} foo-bar 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 prim-
itives as there we do expand.

The scan_word scanner can be used to implement for instance a number scanner:

function token.scan_number(base)
    return tonumber(token.scan_word(),base)
end

This scanner accepts any valid Lua number so it is a way to pick up floats in the input.

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:

command  a number representing the internal command number
cmdname   the type of the command (for instance the catcode in case of a character or the
classifier that determines the internal treatment
csname   the associated control sequence (if applicable)
id       the unique id of the token
active    a boolean indicating the active state of the token
expandable a boolean indicating if the token (macro) is expandable
protected a boolean indicating if the token (macro) is protected

The numbers that represent a catcode are the same as in \TeX itself, so using this information
assumes that you know a bit about \TeX'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.

More interesting are the scanners. 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.scan_dimen()
        ...
    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 \TeX to Lua we letLua fetch from the input stream.

In the first case the input is tokenized and then turned into a string when it’s 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 \TeX 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).

9.6.2 Macros

The set_macro function can get upto 4 arguments:
setmacro("csname","content")
setmacro("csname","content","global")
setmacro("csname")

You can pass a catcodetable identifier as first argument:

setmacro(catcodetable,"csname","content")
setmacro(catcodetable,"csname","content","global")
setmacro(catcodetable,"csname")

The results are like:

\def\csname{content}
\gdef\csname{content}
\def\csname{}

9.6.3 Pushing back

There is a (for now) experimental putter:

local t1 = token.get_next()
local t2 = token.get_next()
local t3 = token.get_next()
local t4 = token.get_next()
-- watch out, we flush in sequence
token.put_next { t1, t2 }
-- but this one gets pushed in front
token.put_next ( t3, t4 )

When we scan wxyz! we get yzwx! back. The argument is either a table with tokens or a list of tokens.

9.6.4 Nota bene

When scanning for the next token you need to keep in mind that we’re not scanning like \TeX does: expanding, changing modes and doing things as it goes. When we scan with Lua we just pick up tokens. Say that we have:

\bar

but \bar is undefined. Normally \TeX will then issue an error message. However, when we have:

\def\foo{\bar}

We get no error, unless we expand \foo while \bar is still undefined. What happens is that as soon as \TeX sees an undefined macro it will create a hash entry and when later it gets defined that entry will be reused. So, \bar really exists but can be in an undefined state.

bar : bar
foo : foo
myfirstbar :

This was entered as:

bar : \directlua{tex.print(token.scan_csname())}\bar
foo : \directlua{tex.print(token.scan_csname())}\foo
myfirstbar : \directlua{tex.print(token.scan_csname())}\myfirstbar

The reason that you see bar reported and not myfirstbar is that \bar was already used in a previous paragraph.

If we now say:
\def\foo{}

we get:

bar : bar
foo : foo
myfirstbar :

And if we say
\def\foo{\bar}

we get:

bar : bar
foo : foo
myfirstbar :

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.

1144399 536941998
1144372 536941998
1144504 536941998

This was generated with:
\directlua{local t = token.get_next() tex.print(t.id.." ..t.tok)}\myfirstbar
\directlua{local t = token.get_next() tex.print(t.id.." ..t.tok)}\mysecondbar
\directlua{local t = token.get_next() tex.print(t.id.." ..t.tok)}\mythirdbar

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.

9.7 The kpse library

This library provides two separate, but nearly identical interfaces to the kpathsea file search functionality: there is a ‘normal’ procedural interface that shares its kpathsea instance with Lua\TeX\ itself, and an object oriented interface that is completely on its own.
9.7.1 kpse.set_program_name and kpse.new

Before the search library can be used at all, its database has to be initialized. There are three possibilities, two of which belong to the procedural interface.

First, when LuaT\TeX is used to typeset documents, this initialization happens automatically and the kpathsea executable and program names are set to luatex (that is, unless explicitly prohibited by the user’s startup script. See section 3.1 for more details).

Second, in \TeXLua mode, the initialization has to be done explicitly via the kpse.set_program_name function, which sets the kpathsea executable (and optionally program) name.

kpse.set_program_name(<string> name)
kps.pset_program_name(<string> name, <string> progname)

The second argument controls the use of the ‘dotted’ values in the texmf.cnf configuration file, and defaults to the first argument.

Third, if you prefer the object oriented interface, you have to call a different function. It has the same arguments, but it returns a userdata variable.

local kpathsea = kpse.new(<string> name)
local kpathsea = kpse.new(<string> name, <string> progname)

Apart from these two functions, the calling conventions of the interfaces are identical. Depending on the chosen interface, you either call kpse.find_file() or kpathsea:find_file(), with identical arguments and return values.

9.7.2 find_file

The most often used function in the library is find_file:

<string> f = kpse.find_file(<string> filename)
<string> f = kpse.find_file(<string> filename, <string> ftype)
<string> f = kpse.find_file(<string> filename, <boolean> mustexist)
<string> f = kpse.find_file(<string> filename, <string> ftype, <boolean> mustexist)
<string> f = kpse.find_file(<string> filename, <string> ftype, <number> dpi)

Arguments:

filename
   the name of the file you want to find, with or without extension.
ftype
   maps to the -format argument of kpsewhich. The supported ftype values are the same as the ones supported by the standalone kpsewhich program: MetaPost support, PostScript header, \TeX system documentation, \TeX system sources, Troff fonts, afm, base, bib, bitmap font, bst, cid maps, clua, cmap files, cnf, cweb, dvips config, enc files, fmt, font feature files, gf, graphic/figure, ist, lig files, ls-R, lua, map, mem, mf, mpool, mft, misc fonts, mlbib, mlbst, mp, mpool, ocp,
ofm, opentype fonts, opl, other binary files, other text files, otp, ovf, ovp, pdftex config, pk, subfont definition files, tex, texmfscripts, texpool, tfm, truetype fonts, type1 fonts, type42 fonts, vf, web, web2c files

The default type is tex. Note: this is different from kpsewhich, which tries to deduce the file type itself from looking at the supplied extension.

mustexist

is similar to kpsewhich’s -must-exist, and the default is false. If you specify true (or a non-zero integer), then the kpse library will search the disk as well as the ls-R databases.

dpi

This is used for the size argument of the formats pk, gf, and bitmap font.

### 9.7.3 lookup

A more powerful (but slower) generic method for finding files is also available. It returns a string for each found file.

```python
<string> f, ... = kpse.lookup(<string> filename, <table> options)
```

The options match commandline arguments from kpsewhich:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>debug</td>
<td>number</td>
<td>set debugging flags for this lookup</td>
</tr>
<tr>
<td>format</td>
<td>string</td>
<td>use specific file type (see list above)</td>
</tr>
<tr>
<td>dpi</td>
<td>number</td>
<td>use this resolution for this lookup; default 600</td>
</tr>
<tr>
<td>path</td>
<td>string</td>
<td>search in the given path</td>
</tr>
<tr>
<td>all</td>
<td>boolean</td>
<td>output all matches, not just the first</td>
</tr>
<tr>
<td>mustexist</td>
<td>boolean</td>
<td>search the disk as well as ls-R if necessary</td>
</tr>
<tr>
<td>mktexpk</td>
<td>boolean</td>
<td>disable/enable mktexpk generation for this lookup</td>
</tr>
<tr>
<td>mkttextex</td>
<td>boolean</td>
<td>disable/enable mkttextex generation for this lookup</td>
</tr>
<tr>
<td>mktexmf</td>
<td>boolean</td>
<td>disable/enable mktexmf generation for this lookup</td>
</tr>
<tr>
<td>mkttextfm</td>
<td>boolean</td>
<td>disable/enable mkttextfm generation for this lookup</td>
</tr>
<tr>
<td>subdir</td>
<td>string or table</td>
<td>only output matches whose directory part ends with the given string(s)</td>
</tr>
</tbody>
</table>

### 9.7.4 init_prog

Extra initialization for programs that need to generate bitmap fonts.

```python
kpse.init_prog(<string> prefix, <number> base_dpi, <string> mfmode)
kpse.init_prog(<string> prefix, <number> base_dpi, <string> mfmode, <string> fallback)
```

### 9.7.5 readable_file

Test if an (absolute) file name is a readable file.

```python
<string> f = kpse.readable_file(<string> name)
```
The return value is the actual absolute filename you should use, because the disk name is not always the same as the requested name, due to aliases and system-specific handling under e.g. msdos. Returns nil if the file does not exist or is not readable.

### 9.7.6 expand_path

Like kpsewhich’s -expand-path:

<string> r = kpse.expand_path(<string> s)

### 9.7.7 expand_var

Like kpsewhich’s -expand-var:

<string> r = kpse.expand_var(<string> s)

### 9.7.8 expand_braces

Like kpsewhich’s -expand-braces:

<string> r = kpse.expand_braces(<string> s)

### 9.7.9 show_path

Like kpsewhich’s -show-path:

<string> r = kpse.show_path(<string> ftype)

### 9.7.10 var_value

Like kpsewhich’s -var-value:

<string> r = kpse.var_value(<string> s)

### 9.7.11 version

Returns the kpathsea version string.

<string> r = kpse.version()
10 The graphic libraries

10.1 The img library

The img library can be used as an alternative to \pdfximage and \pdfrefximage, and the associated ‘satellite’ commands like \pdfximagebbox. Image objects can also be used within virtual fonts via the image command listed in section 5.3.

10.1.1 new

\texttt{\textlt{image} var = img.new()}
\texttt{\textlt{image} var = img.new(\textlt{table} image\_spec)}

This function creates a userdata object of type ‘image’. The image\_spec argument is optional. If it is given, it must be a table, and that table must contain a filename key. A number of other keys can also be useful, these are explained below.

You can either say

\begin{verbatim}
a = img.new()
\end{verbatim}

followed by

\begin{verbatim}
a.filename = "foo.png"
\end{verbatim}

or you can put the file name (and some or all of the other keys) into a table directly, like so:

\begin{verbatim}
a = img.new({filename='foo.pdf', page=1})
\end{verbatim}

The generated \texttt{\textlt{image}} userdata object allows access to a set of user-specified values as well as a set of values that are normally filled in and updated automatically by Lua\TeX\ itself. Some of those are derived from the actual image file, others are updated to reflect the pdf output status of the object.

There is one required user-specified field: the file name (\texttt{filename}). It can optionally be augmented by the requested image dimensions (width, depth, height), user-specified image attributes (attr), the requested pdf page identifier (page), the requested boundingbox (pagebox) for pdf inclusion, the requested color space object (colorspace).

The function \texttt{img.new} does not access the actual image file, it just creates the \texttt{\textlt{image}} userdata object and initializes some memory structures. The \texttt{\textlt{image}} object and its internal structures are automatically garbage collected.

Once the image is scanned, all the values in the \texttt{\textlt{image}} except width, height and depth, become frozen, and you cannot change them any more.

You can use \texttt{pdf.setignoreunknownimages(1)} (or at the \TeX\ end the \texttt{\pdfvariable ignoreunknownimages}) to get around a quit when no known image type is found (based on name or preamble). Beware: this will not catch invalid images and we cannot guarantee side effects.
A zero dimension image is still included when requested. No special flags are set. A proper workflow will not rely in such a catch but make sure that images are valid.

### 10.1.2 keys

```python
<table> keys = img.keys()
```

This function returns a list of all the possible `image_spec` keys, both user-supplied and automatic ones.

<table>
<thead>
<tr>
<th>field name</th>
<th>type</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>attr</td>
<td>string</td>
<td>the image attributes for Lua\TeX{}</td>
</tr>
<tr>
<td>bbox</td>
<td>table</td>
<td>table with 4 bounding box dimensions llx, lly, urx and ury overruling the pagebox entry</td>
</tr>
<tr>
<td>colordepth</td>
<td>number</td>
<td>the number of bits used by the color space</td>
</tr>
<tr>
<td>colorspace</td>
<td>number</td>
<td>the color space object number</td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td>the image depth for Lua\TeX{}</td>
</tr>
<tr>
<td>filename</td>
<td>string</td>
<td>the image file name</td>
</tr>
<tr>
<td>filepath</td>
<td>string</td>
<td>the full (expanded) file name of the image</td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td>the image height for Lua\TeX{}</td>
</tr>
<tr>
<td>imagetype</td>
<td>string</td>
<td>one of pdf, png, jpg, jp2 or jbig2</td>
</tr>
<tr>
<td>index</td>
<td>number</td>
<td>the pdf image name suffix</td>
</tr>
<tr>
<td>objnum</td>
<td>number</td>
<td>the pdf image object number</td>
</tr>
<tr>
<td>page</td>
<td>number</td>
<td>the identifier for the requested image page</td>
</tr>
<tr>
<td>pagebox</td>
<td>string</td>
<td>the requested bounding box, one of none, media, crop, bleed, trim, art</td>
</tr>
<tr>
<td>pages</td>
<td>number</td>
<td>the total number of available pages</td>
</tr>
<tr>
<td>rotation</td>
<td>number</td>
<td>the image rotation from included pdf file, in multiples of 90 deg.</td>
</tr>
<tr>
<td>stream</td>
<td>string</td>
<td>the raw stream data for an /XObject /Form object</td>
</tr>
<tr>
<td>transform</td>
<td>number</td>
<td>the image transform, integer number 0..7</td>
</tr>
<tr>
<td>orientation</td>
<td>number</td>
<td>the (jpeg) image orientation, integer number 1..8 (0 for unset)</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>the image width for Lua\TeX{}</td>
</tr>
<tr>
<td>xres</td>
<td>number</td>
<td>the horizontal natural image resolution (in dpi)</td>
</tr>
<tr>
<td>xsize</td>
<td>number</td>
<td>the natural image width</td>
</tr>
<tr>
<td>yres</td>
<td>number</td>
<td>the vertical natural image resolution (in dpi)</td>
</tr>
<tr>
<td>ysize</td>
<td>number</td>
<td>the natural image height</td>
</tr>
<tr>
<td>visiblefileame</td>
<td>string</td>
<td>when set, this name will find its way in the pdf file as \TeX{} specification; when an empty string is assigned nothing is written to file; otherwise the natural filename is taken</td>
</tr>
</tbody>
</table>

A running (undefined) dimension in width, height, or depth is represented as `nil` in Lua, so if you want to load an image at its ‘natural’ size, you do not have to specify any of those three fields.

The stream parameter allows to fabricate an `/XObject /Form` object from a string giving the stream contents, e.g., for a filled rectangle:

```python
a.stream = "0 0 20 10 re f"
```
When writing the image, an /XObject /Form object is created, like with embedded pdf file writing. The object is written out only once. The stream key requires that also the bbox table is given. The stream key conflicts with the filename key. The transform key works as usual also with stream.

The bbox key needs a table with four boundingbox values, e.g.:

```plaintext
a.bbox = { "30bp", 0, "225bp", "200bp" }
```

This replaces and overrules any given pagebox value; with given bbox the box dimensions coming with an embedded pdf file are ignored. The xsize and ysize dimensions are set accordingly, when the image is scaled. The bbox parameter is ignored for non-pdf images.

The transform allows to mirror and rotate the image in steps of 90 deg. The default value 0 gives an unmirrored, unrotated image. Values 1 – 3 give counterclockwise rotation by 90, 180, or 270 degrees, whereas with values 4 – 7 the image is first mirrored and then rotated counterclockwise by 90, 180, or 270 degrees. The transform operation gives the same visual result as if you would externally preprocess the image by a graphics tool and then use it by LuaTeX. If a pdf file to be embedded already contains a /Rotate specification, the rotation result is the combination of the /Rotate rotation followed by the transform operation.

### 10.1.3 scan

```plaintext
<image> var = img.scan(<image> var)
<image> var = img.scan(<table> image_spec)
```

When you say `img.scan(a)` for a new image, the file is scanned, and variables such as xsize, ysize, image type, number of pages, and the resolution are extracted. Each of the width, height, depth fields are set up according to the image dimensions, if they were not given an explicit value already. An image file will never be scanned more than once for a given image variable. With all subsequent `img.scan(a)` calls only the dimensions are again set up (if they have been changed by the user in the meantime).

For ease of use, you can do right-away a

```plaintext
<image> a = img.scan { filename = "foo.png" }
```

without a prior `img.new`.

Nothing is written yet at this point, so you can do `a=img.scan`, retrieve the available info like image width and height, and then throw away a again by saying `a=nil`. In that case no image object will be reserved in the PDF, and the used memory will be cleaned up automatically.

### 10.1.4 copy

```plaintext
<image> var = img.copy(<image> var)
<image> var = img.copy(<table> image_spec)
```

If you say `a = b`, then both variables point to the same `<image>` object. If you want to write out an image with different sizes, you can do `a b = img.copy(a)`. 
Afterwards, a and b still reference the same actual image dictionary, but the dimensions for b can now be changed from their initial values that were just copies from a.

10.1.5 write

<image> var = img.write(<image> var)
<image> var = img.write(<table> image_spec)

By img.write(a) a pdf object number is allocated, and a whatsit node of subtype pdf_refximage is generated and put into the output list. By this the image a is placed into the page stream, and the image file is written out into an image stream object after the shipping of the current page is finished.

Again you can do a terse call like

img.write { filename = "foo.png" }

The <image> variable is returned in case you want it for later processing.

10.1.6 immediatewrite

<image> var = img.immediatewrite(<image> var)
<image> var = img.immediatewrite(<table> image_spec)

By img.immediatewrite(a) a pdf object number is allocated, and the image file for image a is written out immediately into the pdf file as an image stream object (like with \immediate\pdfximage). The object number of the image stream dictionary is then available by the objnum key. No pdf_refximage whatsit node is generated. You will need an img.write(a) or img.node(a) call to let the image appear on the page, or reference it by another trick; else you will have a dangling image object in the pdf file.

Also here you can do a terse call like

a = img.immediatewrite { filename = "foo.png" }

The <image> variable is returned and you will most likely need it.

10.1.7 node

<node> n = img.node(<image> var)
<node> n = img.node(<table> image_spec)

This function allocates a pdf object number and returns a whatsit node of subtype pdf_refximage, filled with the image parameters width, height, depth, and objnum. Also here you can do a terse call like:

n = img.node ({ filename = "foo.png" })

This example outputs an image:
node.write(img.node{filename="foo.png"})

10.1.8 types
<table> types = img.types()

This function returns a list with the supported image file type names, currently these are pdf, png, jpg, jp2 (JPEG 2000), and jbig2.

10.1.9 boxes
<table> boxes = img.boxes()

This function returns a list with the supported pdf page box names, currently these are media, crop, bleed, trim, and art, all in lowercase letters.

10.2 The mplib library

The MetaPost library interface registers itself in the table mplib. It is based on mplib version 1.9991.

10.2.1 new

To create a new MetaPost instance, call
<mpinstance> mp = mplib.new({...})

This creates the mp instance object. The argument hash can have a number of different fields, as follows:

<table>
<thead>
<tr>
<th>name</th>
<th>type</th>
<th>description</th>
<th>default</th>
</tr>
</thead>
<tbody>
<tr>
<td>error_line</td>
<td>number</td>
<td>error line width</td>
<td>79</td>
</tr>
<tr>
<td>print_line</td>
<td>number</td>
<td>line length in ps output</td>
<td>100</td>
</tr>
<tr>
<td>random_seed</td>
<td>number</td>
<td>the initial random seed</td>
<td>variable</td>
</tr>
<tr>
<td>math_mode</td>
<td>string</td>
<td>the number system to use: double, scaled, binary or decimal</td>
<td>scaled</td>
</tr>
<tr>
<td>interaction</td>
<td>string</td>
<td>the interaction mode: batch, non-stop, scroll or errorstop</td>
<td>errorstop</td>
</tr>
<tr>
<td>job_name</td>
<td>string</td>
<td>--jobname</td>
<td>mpout</td>
</tr>
<tr>
<td>find_file</td>
<td>function</td>
<td>a function to find files</td>
<td>only local files</td>
</tr>
</tbody>
</table>

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 mp:execute() call.

10.2.2  mp: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:

- 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.

10.2.3  mp:execute

You can ask the MetaPost interpreter to run a chunk of code by calling
<table> rettable = mp:execute('metapost language chunk')

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.

10.2.4  mp:finish

<table> rettable = mp:finish()

If for some reason you want to stop using an mplib instance while processing is not yet actually done, you can call mp:finish. Eventually, used memory will be freed and open files will be closed.
by the Lua garbage collector, but an explicit mp:finish is the only way to capture the final part of the output streams.

10.2.5 Result table

The return value of mp:execute and mp:finish is a table with a few possible keys (only status is always guaranteed to be present).

<table>
<thead>
<tr>
<th>Key</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>log</td>
<td>string output to the ‘log’ stream</td>
</tr>
<tr>
<td>term</td>
<td>string output to the ‘term’ stream</td>
</tr>
<tr>
<td>error</td>
<td>string output to the ‘error’ stream (only used for ‘out of memory’)</td>
</tr>
<tr>
<td>status</td>
<td>the return value: 0 = good, 1 = warning, 2 = errors, 3 = fatal error</td>
</tr>
<tr>
<td>fig</td>
<td>table an array of generated figures (if any)</td>
</tr>
</tbody>
</table>

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:

- boundingbox function returns the bounding box, as an array of 4 values
- postscript function returns a string that is the ps output of the fig. This function accepts two optional integer arguments for specifying the values of prologues (first argument) and procset (second argument)
- svg function returns a string that is the svg output of the fig. This function accepts an optional integer argument for specifying the value of prologues
- objects function returns the actual array of graphic objects in this fig
- copy_objects function returns a deep copy of the array of graphic objects in this fig
- filename function the filename this fig’s PostScript output would have written to in stand alone mode
- width function the fontcharwd value
- height function the fontcharht value
- depth function the fontchardp value
- italcorr 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 that each has a different list of accessible values. The types are: fill, outline, text, start_clip, stop_clip, start_bounds, stop_bounds, special.

There is 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.
### 10.2.5.1 Fill

<table>
<thead>
<tr>
<th>Term</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>path</td>
<td>table</td>
<td>the list of knots</td>
</tr>
<tr>
<td>htap</td>
<td>table</td>
<td>the list of knots for the reversed trajectory</td>
</tr>
<tr>
<td>pen</td>
<td>table</td>
<td>knots of the pen</td>
</tr>
<tr>
<td>color</td>
<td>table</td>
<td>the object’s color</td>
</tr>
<tr>
<td>linejoin</td>
<td>number</td>
<td>line join style (bare number)</td>
</tr>
<tr>
<td>miterlimit</td>
<td>number</td>
<td>miterlimit</td>
</tr>
<tr>
<td>prescript</td>
<td>string</td>
<td>the prescript text</td>
</tr>
<tr>
<td>postscript</td>
<td>string</td>
<td>the postscript text</td>
</tr>
</tbody>
</table>

The entries htap and pen are optional.

There is helper function `mplib.pen_info(obj)` that returns a table containing a bunch of vital characteristics of the used pen (all values are floats):

<table>
<thead>
<tr>
<th>Term</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>width</td>
<td>number</td>
<td>width of the pen</td>
</tr>
<tr>
<td>sx</td>
<td>number</td>
<td>( x ) scale</td>
</tr>
<tr>
<td>rx</td>
<td>number</td>
<td>( xy ) multiplier</td>
</tr>
<tr>
<td>ry</td>
<td>number</td>
<td>( yx ) multiplier</td>
</tr>
<tr>
<td>sy</td>
<td>number</td>
<td>( y ) scale</td>
</tr>
<tr>
<td>tx</td>
<td>number</td>
<td>( x ) offset</td>
</tr>
<tr>
<td>ty</td>
<td>number</td>
<td>( y ) offset</td>
</tr>
</tbody>
</table>

### 10.2.5.2 Outline

<table>
<thead>
<tr>
<th>Term</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>path</td>
<td>table</td>
<td>the list of knots</td>
</tr>
<tr>
<td>pen</td>
<td>table</td>
<td>knots of the pen</td>
</tr>
<tr>
<td>color</td>
<td>table</td>
<td>the object’s color</td>
</tr>
<tr>
<td>linejoin</td>
<td>number</td>
<td>line join style (bare number)</td>
</tr>
<tr>
<td>miterlimit</td>
<td>number</td>
<td>miterlimit</td>
</tr>
<tr>
<td>linecap</td>
<td>number</td>
<td>line cap style (bare number)</td>
</tr>
<tr>
<td>dash</td>
<td>table</td>
<td>representation of a dash list</td>
</tr>
<tr>
<td>prescript</td>
<td>string</td>
<td>the prescript text</td>
</tr>
<tr>
<td>postscript</td>
<td>string</td>
<td>the postscript text</td>
</tr>
</tbody>
</table>

The entry dash is optional.

### 10.2.5.3 Text

<table>
<thead>
<tr>
<th>Term</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>text</td>
<td>string</td>
<td>the text</td>
</tr>
<tr>
<td>font</td>
<td>string</td>
<td>font ttfm name</td>
</tr>
<tr>
<td>dsize</td>
<td>number</td>
<td>font size</td>
</tr>
<tr>
<td>color</td>
<td>table</td>
<td>the object’s color</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>height</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>depth</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>transform</td>
<td>table</td>
<td>a text transformation</td>
</tr>
</tbody>
</table>
prescript string the prescript text
postscript string the postscript text

10.2.5.4 special

prescript string special text

10.2.5.5 start_bounds, start_clip

path table the list of knots

10.2.5.6 stop_bounds, stop_clip

Here are no fields available.

10.2.6 Subsidiary table formats

10.2.6.1 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.

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
left_y number Y coordinate of the precontrol point of this knot
right_x number X coordinate of the postcontrol point of this knot
right_y number Y coordinate of the postcontrol point of this knot

There is one special case: pens that are (possibly transformed) ellipses have an extra string-valued key type with value elliptical besides the array part containing the knot list.

10.2.6.2 Colors

A color is an integer array with 0, 1, 3 or 4 values:

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 cmyk 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.
10.2.6.3 Transforms

Each transform is a six-item array.

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.

10.2.6.4 Dashes

Each dash is two-item hash, using 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.

dashes hash an array of on-off numbers
offset number the starting offset value

10.2.7 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.

10.2.7.1 mp:char_width

<number> w = mp:char_width(<string> fontname, <number> char)

10.2.7.2 mp:char_height

<number> w = mp:char_height(<string> fontname, <number> char)

10.2.7.3 mp:char_depth

<number> w = mp:char_depth(<string> fontname, <number> char)
11 The fontloader

The fontloader library is sort of independent of the rest in the sense that it can load font into a Lua table that then can be converted into a table suitable for \TeX. The library is an adapted subset of FontForge and as such gives a similar view on a font (which has advantages when you want to debug.)

11.1 Getting quick information on a font

When you want to locate font by name you need some basic information that is hidden in the font files. For that reason we provide an efficient helper that gets the basic information without loading all of the font. Normally this helper is used to create a font (name) database.

\begin{verbatim}
<table> info = 
  fontloader.info(<string> filename)
\end{verbatim}

This function returns either nil, or a table, or an array of small tables (in the case of a TrueType collection). The returned table(s) will contain some fairly interesting information items from the font(s) defined by the file:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>fontname</td>
<td>string</td>
<td>the PostScript name of the font</td>
</tr>
<tr>
<td>fullname</td>
<td>string</td>
<td>the formal name of the font</td>
</tr>
<tr>
<td>familyname</td>
<td>string</td>
<td>the family name this font belongs to</td>
</tr>
<tr>
<td>weight</td>
<td>string</td>
<td>a string indicating the color value of the font</td>
</tr>
<tr>
<td>version</td>
<td>string</td>
<td>the internal font version</td>
</tr>
<tr>
<td>italicangle</td>
<td>float</td>
<td>the slant angle</td>
</tr>
<tr>
<td>units_per_em</td>
<td>number</td>
<td>1000 for PostScript-based fonts, usually 2048 for TrueType</td>
</tr>
<tr>
<td>pfminfo</td>
<td>table</td>
<td>(see section 11.6.6)</td>
</tr>
</tbody>
</table>

Getting information through this function is (sometimes much) more efficient than loading the font properly, and is therefore handy when you want to create a dictionary of available fonts based on a directory contents.

11.2 Loading an OPENTYPE or TRUETYPE file

If you want to use an OpenType font, you have to get the metric information from somewhere. Using the fontloader library, the simplest way to get that information is thus:

\begin{verbatim}
function load_font (filename)
  local metrics = nil
  local font = fontloader.open(filename)
  if font then
    metrics = fontloader.to_table(font)
    fontloader.close(font)
  end
\end{verbatim}
return metrics
end

myfont = load_font('/opt/tex/texmf/fonts/data/arial.ttf')

The main function call is

<userdata> f, <table> w = fontloader.open(<string> filename)
<userdata> f, <table> w = fontloader.open(<string> filename, <string> fontname)

The first return value is a userdata representation of the font. The second return value is a table containing any warnings and errors reported by fontloader while opening the font. In normal typesetting, you would probably ignore the second argument, but it can be useful for debugging purposes.

For TrueType collections (when filename ends in 'ttc') and dfont collections, you have to use a second string argument to specify which font you want from the collection. Use the fontname strings that are returned by fontloader.info for that.

To turn the font into a table, fontloader.to_table is used on the font returned by fontloader.open.

<table> f = fontloader.to_table(<userdata> font)

This table cannot be used directly by LuaTeX and should be turned into another one as described in chapter 5. Do not forget to store the fontname value in the psname field of the metrics table to be returned to LuaTeX, otherwise the font inclusion backend will not be able to find the correct font in the collection.

See section 11.5 for details on the userdata object returned by fontloader.open() and the layout of the metrics table returned by fontloader.to_table().

The font file is parsed and partially interpreted by the font loading routines from FontForge. The file format can be OpenType, TrueType, TrueType Collection, cff, or Type1.

There are a few advantages to this approach compared to reading the actual font file ourselves:

- The font is automatically re-encoded, so that the metrics table for TrueType and OpenType fonts is using Unicode for the character indices.
- Many features are pre-processed into a format that is easier to handle than just the bare tables would be.
- PostScript-based OpenType fonts do not store the character height and depth in the font file, so the character boundingbox has to be calculated in some way.
- In the future, it may be interesting to allow Lua scripts access to the font program itself, perhaps even creating or changing the font.

A loaded font is discarded with:

fontloader.close(<userdata> font)

## 11.3 Applying a ‘feature file’

You can apply a ‘feature file’ to a loaded font:

If the function fails, the return value is a table containing any errors reported by fontloader while applying the feature file. On success, nil is returned.

### 11.4 Applying an ‘AFM file’

You can apply an ‘afm file’ to a loaded font:

```plaintext
<table> errors = fontloader.apply_afmfile(<userdata> font, <string> filename)
```

An afm file is a textual representation of (some of) the meta information in a Type1 font. See ftp://ftp.math.utah.edu/u/ma/hohn/linux/postscript/5004.AFM_Spec.pdf for more information about afm files.

Note: If you `fontloader.open()` a Type1 file named `font.pfb`, the library will automatically search for and apply `font.afm` if it exists in the same directory as the file `font.pfb`. In that case, there is no need for an explicit call to `apply_afmfile()`.

If the function fails, the return value is a table containing any errors reported by fontloader while applying the AFM file. On success, nil is returned.

### 11.5 Fontloader font tables

As mentioned earlier, the return value of `fontloader.open()` is a userdata object. One way to have access to the actual metrics is to call `fontloader.to_table()` on this object, returning the table structure that is explained in the following sections. In the following sections we will not explain each field in detail. Most fields are self-descriptive and for the more technical aspects you need to consult the relevant font references.

It turns out that the result from `fontloader.to_table()` sometimes needs very large amounts of memory (depending on the font’s complexity and size) so it is possible to access the userdata object directly.

- All top-level keys that would be returned by `to_table()` can also be accessed directly.
- The top-level key ‘glyphs’ returns a *virtual* array that allows indices from `f.glyphmin` to `f.glyphmax`.

```plaintext
•
```
• The items in that virtual array (the actual glyphs) are themselves also userdata objects, and each has accessors for all of the keys explained in the section ‘Glyph items’ below.
• The top-level key ‘subfonts’ returns an actual array of userdata objects, one for each of the subfonts (or nil, if there are no subfonts).

A short example may be helpful. This code generates a printout of all the glyph names in the font PunkNova.kern.otf:

```lua
local f = fontloader.open('PunkNova.kern.otf')
print (f.fontname)
local i = 0
if f.glyphcnt > 0 then
    for i=f.glyphmin,f.glyphmax do
        local g = f.glyphs[i]
        if g then
            print(g.name)
        end
        i = i + 1
    end
end
fontloader.close(f)
```

In this case, the LuaTEX memory requirement stays below 100MB on the test computer, while the internal structure generated by to_table() needs more than 2GB of memory (the font itself is 6.9MB in disk size).

Only the top-level font, the subfont table entries, and the glyphs are virtual objects, everything else still produces normal Lua values and tables.

If you want to know the valid fields in a font or glyph structure, call the fields function on an object of a particular type (either glyph or font):

```lua
<table> fields = fontloader.fields(<userdata> font)
<table> fields = fontloader.fields(<userdata> font_glyph)
```

For instance:

```lua
local fields = fontloader.fields(f)
local fields = fontloader.fields(f.glyphs[0])
```

### 11.6 Table types

#### 11.6.1 Top-level

The top-level keys in the returned table are (the explanations in this part of the documentation are not yet finished):

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>table_version</td>
<td>number</td>
<td>indicates the metrics version (currently 0.3)</td>
</tr>
<tr>
<td>Variable</td>
<td>Type</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>fontname</td>
<td>string</td>
<td>PostScript font name</td>
</tr>
<tr>
<td>fullname</td>
<td>string</td>
<td>official (human-oriented) font name</td>
</tr>
<tr>
<td>familyname</td>
<td>string</td>
<td>family name</td>
</tr>
<tr>
<td>weight</td>
<td>string</td>
<td>weight indicator</td>
</tr>
<tr>
<td>copyright</td>
<td>string</td>
<td>copyright information</td>
</tr>
<tr>
<td>filename</td>
<td>string</td>
<td>the file name</td>
</tr>
<tr>
<td>version</td>
<td>string</td>
<td>font version</td>
</tr>
<tr>
<td>italicangle</td>
<td>float</td>
<td>slant angle</td>
</tr>
<tr>
<td>units_per_em</td>
<td>number</td>
<td>1000 for PostScript-based fonts, usually 2048 for TrueType</td>
</tr>
<tr>
<td>ascent</td>
<td>number</td>
<td>height of ascender in units_per_em</td>
</tr>
<tr>
<td>descent</td>
<td>number</td>
<td>depth of descender in units_per_em</td>
</tr>
<tr>
<td>upos</td>
<td>float</td>
<td></td>
</tr>
<tr>
<td>uwidth</td>
<td>float</td>
<td></td>
</tr>
<tr>
<td>uniqueid</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>glyphs</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>glyphcnt</td>
<td>number</td>
<td>number of included glyphs</td>
</tr>
<tr>
<td>glyphmax</td>
<td>number</td>
<td>maximum used index the glyphs array</td>
</tr>
<tr>
<td>glyphmin</td>
<td>number</td>
<td>minimum used index the glyphs array</td>
</tr>
<tr>
<td>notdef_loc</td>
<td>number</td>
<td>location of the .notdef glyph or -1 when not present</td>
</tr>
<tr>
<td>hasvmetrics</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>onlybitmaps</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>serifcheck</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>isserif</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>issans</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>encodingchanged</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>strokedfont</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>use_typo_metrics</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>weight_width_slope_only</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>head_optimized_for_cleartype</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>uni_interp</td>
<td>enum</td>
<td>unset, none, adobe, greek, japanese, trad_chinese, simp_chinese, korean, ams</td>
</tr>
<tr>
<td>origname</td>
<td>string</td>
<td>the file name, as supplied by the user</td>
</tr>
<tr>
<td>map</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>private</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>xuid</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>pfminfo</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>names</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>cidinfo</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>subfonts</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>comments</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>fontlog</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>cvt_names</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>anchor_classes</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>ttf_tables</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>ttf_tab_saved</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>
11.6.2 Glyph items

The glyphs is an array containing the per-character information (quite a few of these are only present if nonzero).

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>string</td>
<td>the glyph name</td>
</tr>
<tr>
<td>unicode</td>
<td>number</td>
<td>unicode code point, or -1</td>
</tr>
<tr>
<td>boundingbox</td>
<td>array</td>
<td>array of four numbers, see note below</td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td>only for horizontal fonts</td>
</tr>
<tr>
<td>vwidth</td>
<td>number</td>
<td>only for vertical fonts</td>
</tr>
<tr>
<td>tsidebearing</td>
<td>number</td>
<td>only for vertical ttf/otf fonts, and only if nonzero</td>
</tr>
<tr>
<td>lsidebearing</td>
<td>number</td>
<td>only if nonzero and not equal to boundingbox[1]</td>
</tr>
<tr>
<td>class</td>
<td>string</td>
<td>one of &quot;none&quot;, &quot;base&quot;, &quot;ligature&quot;, &quot;mark&quot;, &quot;component&quot; (if not present, the glyph class is ‘automatic’)</td>
</tr>
<tr>
<td>kerns</td>
<td>array</td>
<td>only for horizontal fonts, if set</td>
</tr>
<tr>
<td>vkerns</td>
<td>array</td>
<td>only for vertical fonts, if set</td>
</tr>
<tr>
<td>dependents</td>
<td>array</td>
<td>linear array of glyph name strings, only if nonempty</td>
</tr>
<tr>
<td>lookups</td>
<td>table</td>
<td>only if nonempty</td>
</tr>
<tr>
<td>ligatures</td>
<td>table</td>
<td>only if nonempty</td>
</tr>
<tr>
<td>anchors</td>
<td>table</td>
<td>only if set</td>
</tr>
</tbody>
</table>
comment string only if set
tex_height number only if set
tex_depth number only if set
italic_correction number only if set
top_accent number only if set
is_extended_shape number only if this character is part of a math extension list
altuni table alternate Unicode items
vert_variants table
horiz_variants table
mathkern table

On boundingbox: The boundingbox information for TrueType fonts and TrueType-based otf fonts is read directly from the font file. PostScript-based fonts do not have this information, so the boundingbox of traditional PostScript fonts is generated by interpreting the actual bezier curves to find the exact boundingbox. This can be a slow process, so the boundingboxes of PostScript-based otf fonts (and raw cff fonts) are calculated using an approximation of the glyph shape based on the actual glyph points only, instead of taking the whole curve into account. This means that glyphs that have missing points at extrema will have a too-tight boundingbox, but the processing is so much faster that in our opinion the tradeoff is worth it.

The kerns and vkerns are linear arrays of small hashes:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>char</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>off</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>lookup</td>
<td>string</td>
<td></td>
</tr>
</tbody>
</table>

The lookups is a hash, based on lookup subtable names, with the value of each key inside that a linear array of small hashes:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>enum</td>
<td>position, pair, substitution, alternate, multiple, ligature, lcaret, kerning, vkerning, anchors, contextpos, contextsub, chainpos, chain-sub, reversesub, max, kernback, vkernback</td>
</tr>
</tbody>
</table>

specification table extra data

For the first seven values of type, there can be additional sub-information, stored in the sub-table specification:

<table>
<thead>
<tr>
<th>value</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>position</td>
<td>table</td>
<td>a table of the offset_specs type</td>
</tr>
<tr>
<td>pair</td>
<td>table</td>
<td>one string: paired, and an array of one or two offset_specs tables: offsets</td>
</tr>
<tr>
<td>substitution</td>
<td>table</td>
<td>one string: variant</td>
</tr>
<tr>
<td>alternate</td>
<td>table</td>
<td>one string: components</td>
</tr>
<tr>
<td>multiple</td>
<td>table</td>
<td>one string: components</td>
</tr>
<tr>
<td>ligature</td>
<td>table</td>
<td>two strings: components, char</td>
</tr>
<tr>
<td>lcaret</td>
<td>array</td>
<td>linear array of numbers</td>
</tr>
</tbody>
</table>
Tables for offset_specs contain up to four number-valued fields: x (a horizontal offset), y (a vertical offset), h (an advance width correction) and v (an advance height correction).

The ligatures is a linear array of small hashes:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>lig</td>
<td>table</td>
<td>uses the same substructure as a single item in the lookups table explained above</td>
</tr>
<tr>
<td>char</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>components</td>
<td>array</td>
<td>linear array of named components</td>
</tr>
<tr>
<td>ccnt</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

The anchor table is indexed by a string signifying the anchor type, which is one of:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>mark</td>
<td>table</td>
<td>placement mark</td>
</tr>
<tr>
<td>basechar</td>
<td>table</td>
<td>mark for attaching combining items to a base char</td>
</tr>
<tr>
<td>baselig</td>
<td>table</td>
<td>mark for attaching combining items to a ligature</td>
</tr>
<tr>
<td>basemark</td>
<td>table</td>
<td>generic mark for attaching combining items to connect to</td>
</tr>
<tr>
<td>centry</td>
<td>table</td>
<td>cursive entry point</td>
</tr>
<tr>
<td>cexit</td>
<td>table</td>
<td>cursive exit point</td>
</tr>
</tbody>
</table>

The content of these is a short array of defined anchors, with the entry keys being the anchor names. For all except baselig, the value is a single table with this definition:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>number</td>
<td>x location</td>
</tr>
<tr>
<td>y</td>
<td>number</td>
<td>y location</td>
</tr>
<tr>
<td>ttf_pt_index</td>
<td>number</td>
<td>truetype point index, only if given</td>
</tr>
</tbody>
</table>

For baselig, the value is a small array of such anchor sets sets, one for each constituent item of the ligature.

For clarification, an anchor table could for example look like this:

```javascript
['anchor'] = {
    ['basemark'] = {
        ['Anchor-7'] = { ['x']=170, ['y']=1080 }
    },
    ['mark'] ={
        ['Anchor-1'] = { ['x']=160, ['y']=810 },
        ['Anchor-4'] = { ['x']=160, ['y']=800 }
    },
    ['baselig'] = {
        [1] = { ['Anchor-2'] = { ['x']=160, ['y']=650 } },
        [2] = { ['Anchor-2'] = { ['x']=460, ['y']=640 } }
    }
}
```

Note: The baselig table can be sparse!
11.6.3 map table

The top-level map is a list of encoding mappings. Each of those is a table itself.

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>enccount</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>encmax</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>backmax</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>remap</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>map</td>
<td>array</td>
<td>non-linear array of mappings</td>
</tr>
<tr>
<td>backmap</td>
<td>array</td>
<td>non-linear array of backward mappings</td>
</tr>
<tr>
<td>enc</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The remap table is very small:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>firstenc</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>lastenc</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>infont</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

The enc table is a bit more verbose:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>enc_name</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>char_cnt</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>char_max</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>unicode</td>
<td>array</td>
<td>of Unicode position numbers</td>
</tr>
<tr>
<td>psnames</td>
<td>array</td>
<td>of PostScript glyph names</td>
</tr>
<tr>
<td>builtin</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hidden</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>only_1byte</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>has_1byte</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>has_2byte</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>is_unicodebmp</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_unidodefull</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_custom</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_original</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_compact</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_japanese</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_korean</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>is_tradchinese</td>
<td>number</td>
<td>only if nonzero [name?]</td>
</tr>
<tr>
<td>is_simplechinese</td>
<td>number</td>
<td>only if nonzero</td>
</tr>
<tr>
<td>low_page</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>high_page</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>iconv_name</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>iso_2022_escape</td>
<td>string</td>
<td></td>
</tr>
</tbody>
</table>
11.6.4 private table

This is the font’s private PostScript dictionary, if any. Keys and values are both strings.

11.6.5 cidinfo table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>registry</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>ordering</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>supplement</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>version</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

11.6.6 pfminfo table

The pfminfo table contains most of the OS/2 information:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>pfmset</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>winascent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>windescent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hheadascent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hheaddescent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>typoascent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>typodescent_add</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>subsuper_set</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>panose_set</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hheadset</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>vheadset</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>pfmfamily</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>width</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>avgwidth</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>firstchar</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>lastchar</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>fstype</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>linegap</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>vlinegap</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hhead_ascent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>hhead_descent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_typoascent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_typodescent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_typolinegap</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_winascent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_windescent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_subxsize</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>os2_subysize</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>
The fontloader

os2_subxoff number
os2_subyoff number
os2_supxsize number
os2_supysize number
os2_supxoff number
os2_supyoff number
os2_strikeysize number
os2_strikeypos number
os2_family_class number
os2_xheight number
os2_capheight number
os2_defaultchar number
os2_breakchar number
os2_vendor string
codepages table A two-number array of encoded code pages
unicoderages table A four-number array of encoded unicode ranges
panose table

The panose subtable has exactly 10 string keys:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>familytype</td>
<td>string</td>
<td>Values as in the OpenType font specification: Any, No Fit, Text and Display, Script, Decorative, Pictorial</td>
</tr>
<tr>
<td>serifstyle</td>
<td>string</td>
<td>See the OpenType font specification for values</td>
</tr>
<tr>
<td>weight</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>proportion</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>contrast</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>strokevariation</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>armstyle</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>letterform</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>midline</td>
<td>string</td>
<td>id.</td>
</tr>
<tr>
<td>xheight</td>
<td>string</td>
<td>id.</td>
</tr>
</tbody>
</table>

11.6.7 names table

Each item has two top-level keys:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>lang</td>
<td>string</td>
<td>language for this entry</td>
</tr>
<tr>
<td>names</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The names keys are the actual TrueType name strings. The possible keys are:

<table>
<thead>
<tr>
<th>key</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>copyright</td>
<td></td>
</tr>
<tr>
<td>family</td>
<td></td>
</tr>
<tr>
<td>subfamily</td>
<td></td>
</tr>
</tbody>
</table>
11.6.8 anchor_classes table

The anchor_classes classes:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>string</td>
<td>a descriptive id of this anchor class</td>
</tr>
<tr>
<td>lookup</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>type</td>
<td>string</td>
<td>one of mark, mkmk, curs, mklg</td>
</tr>
</tbody>
</table>

11.6.9 gpos table

The gpos table has one array entry for each lookup. (The gpos_prefix is somewhat redundant.)

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>string</td>
<td>one of gpos_single, gpos_pair, gpos_cursive, gpos_mark2base,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>gpos_mark2ligature, gpos_mark2mark, gpos_context,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>gpos_contextchain</td>
</tr>
<tr>
<td>flags</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>name</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>features</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>subtables</td>
<td>array</td>
<td></td>
</tr>
</tbody>
</table>

The flags table has a true value for each of the lookup flags that is actually set:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>r2l</td>
<td>boolean</td>
<td></td>
</tr>
</tbody>
</table>
ignorebaseglyphs  boolean
ignoreligatures  boolean
ignorecombiningmarks  boolean
mark_class  string

The features subtable items of gpos have:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>tag</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>scripts</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The scripts table within features has:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>script</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>langs</td>
<td>array of strings</td>
<td></td>
</tr>
</tbody>
</table>

The subtables table has:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>suffix</td>
<td>string</td>
<td>(only if used)</td>
</tr>
<tr>
<td>anchor_classes</td>
<td>number</td>
<td>(only if used)</td>
</tr>
<tr>
<td>vertical_kerning</td>
<td>number</td>
<td>(only if used)</td>
</tr>
<tr>
<td>kernclass</td>
<td>table</td>
<td>(only if used)</td>
</tr>
</tbody>
</table>

The kernclass with subtables table has:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>firsts</td>
<td>array of strings</td>
<td></td>
</tr>
<tr>
<td>seconds</td>
<td>array of strings</td>
<td></td>
</tr>
<tr>
<td>lookup</td>
<td>string or array</td>
<td>associated lookup(s)</td>
</tr>
<tr>
<td>offsets</td>
<td>array of numbers</td>
<td></td>
</tr>
</tbody>
</table>

Note: the kernclass (as far as we can see) always has one entry so it could be one level deep instead. Also the seconds start at [2] which is close to the fontforge internals so we keep that too.

11.6.10  gsub table

This has identical layout to the gpos table, except for the type:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>string</td>
<td>one of gsub_single, gsub_multiple, gsub_alternate, gsub_ligature, gsub_context, gsub_contextchain, gsub_reversecontextchain</td>
</tr>
</tbody>
</table>

11.6.11  ttf_tables and ttf_tab_saved tables

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>tag</td>
<td>string</td>
<td></td>
</tr>
</tbody>
</table>
The fontloader

11.6.12 mm table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>axes</td>
<td>table</td>
<td>array of axis names</td>
</tr>
<tr>
<td>instance_count</td>
<td>number</td>
<td>array of instance positions (#axes * instances )</td>
</tr>
<tr>
<td>positions</td>
<td>table</td>
<td>array of default weights for instances</td>
</tr>
<tr>
<td>defweights</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>cdv</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>ndv</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>axismaps</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The axismaps:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>blends</td>
<td>table</td>
<td>an array of blend points</td>
</tr>
<tr>
<td>designs</td>
<td>table</td>
<td>an array of design values</td>
</tr>
<tr>
<td>min</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>def</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>max</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

11.6.13 mark_classes table

The keys in this table are mark class names, and the values are a space-separated string of glyph names in this class.

11.6.14 math table

ScriptPercentScaleDown
ScriptScriptPercentScaleDown
DelimitedSubFormulaMinHeight
DisplayOperatorMinHeight
MathLeading
AxisHeight
AccentBaseHeight
FlattenedAccentBaseHeight
SubscriptShiftDown
SubscriptTopMax
SubscriptBaselineDropMin
SuperscriptShiftUp
SuperscriptShiftUpCramped
SuperscriptBaselineDropMax
SubSuperscriptGapMin
SuperscriptBottomMaxWithSubscript
SpaceAfterScript
UpperLimitGapMin
UpperLimitBaselineRiseMin
LowerLimitGapMin
LowerLimitBaselineDropMin
StackTopShiftUp
StackTopDisplayStyleShiftUp
StackBottomShiftDown
StackBottomDisplayStyleShiftDown
StackGapMin
StackDisplayStyleGapMin
StretchStackTopShiftUp
StretchStackBottomShiftDown
StretchStackGapAboveMin
StretchStackGapBelowMin
FractionNumeratorShiftUp
FractionNumeratorDisplayStyleShiftUp
FractionDenominatorShiftDown
FractionDenominatorDisplayStyleShiftDown
FractionNumeratorGapMin
FractionNumeratorDisplayStyleGapMin
FractionRuleThickness
FractionDenominatorGapMin
FractionDenominatorDisplayStyleGapMin
SkewedFractionHorizontalGap
SkewedFractionVerticalGap
OverbarVerticalGap
OverbarRuleThickness
OverbarExtraAscender
UnderbarVerticalGap
UnderbarRuleThickness
UnderbarExtraDescender
RadicalVerticalGap
RadicalDisplayStyleVerticalGap
RadicalRuleThickness
RadicalExtraAscender
RadicalKernBeforeDegree
RadicalKernAfterDegree
RadicalDegreeBottomRaisePercent
MinConnectorOverlap
FractionDelimiterSize
FractionDelimiterDisplayStyleSize
11.6.15 validation_state table

<table>
<thead>
<tr>
<th>key</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>bad_ps_fontname</td>
<td></td>
</tr>
<tr>
<td>bad_glyph_table</td>
<td></td>
</tr>
<tr>
<td>bad_cff_table</td>
<td></td>
</tr>
<tr>
<td>bad_metrics_table</td>
<td></td>
</tr>
<tr>
<td>bad_cmap_table</td>
<td></td>
</tr>
<tr>
<td>bad_bitmaps_table</td>
<td></td>
</tr>
<tr>
<td>bad_gx_table</td>
<td></td>
</tr>
<tr>
<td>bad_ot_table</td>
<td></td>
</tr>
<tr>
<td>bad_os2_version</td>
<td></td>
</tr>
<tr>
<td>bad_sfnt_header</td>
<td></td>
</tr>
</tbody>
</table>

11.6.16 horiz_base and vert_base table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>tags</td>
<td>table</td>
<td>an array of script list tags</td>
</tr>
<tr>
<td>scripts</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The scripts subtable:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>default_baseline</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>lang</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The lang subtable:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>tag</td>
<td>string</td>
<td>a script tag</td>
</tr>
<tr>
<td>ascent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>descent</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>features</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The features points to an array of tables with the same layout except that in those nested tables, the tag represents a language.

11.6.17 altuni table

An array of alternate Unicode values. Inside that array are hashes with:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>unicode</td>
<td>number</td>
<td>this glyph is also used for this unicode</td>
</tr>
<tr>
<td>variant</td>
<td>number</td>
<td>the alternative is driven by this unicode selector</td>
</tr>
</tbody>
</table>
11.6.18 vert_variants and horiz_variants table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>variants</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>italic_correction</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>parts</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

The parts table is an array of smaller tables:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>component</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>extender</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>start</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>end</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>advance</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

11.6.19 mathkern table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>top_right</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>bottom_right</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>top_left</td>
<td>table</td>
<td></td>
</tr>
<tr>
<td>bottom_left</td>
<td>table</td>
<td></td>
</tr>
</tbody>
</table>

Each of the subtables is an array of small hashes with two keys:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>height</td>
<td>number</td>
<td></td>
</tr>
<tr>
<td>kern</td>
<td>number</td>
<td></td>
</tr>
</tbody>
</table>

11.6.20 kerns table

Substructure is identical to the per-glyph subtable.

11.6.21 vkernels table

Substructure is identical to the per-glyph subtable.

11.6.22 texdata table

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>string</td>
<td>unset, text, math, mathext</td>
</tr>
<tr>
<td>params</td>
<td>array</td>
<td>22 font numeric parameters</td>
</tr>
</tbody>
</table>

11.6.23 lookups table

Top-level lookups is quite different from the ones at character level. The keys in this hash are strings, the values the actual lookups, represented as dictionary tables.
<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>format</td>
<td>enum</td>
<td>one of glyphs, class, coverage, reversecoverage</td>
</tr>
<tr>
<td>tag</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>current_class</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>before_class</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>after_class</td>
<td>array</td>
<td></td>
</tr>
<tr>
<td>rules</td>
<td>array</td>
<td>an array of rule items</td>
</tr>
</tbody>
</table>

Rule items have one common item and one specialized item:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>lookups</td>
<td>array</td>
<td>a linear array of lookup names</td>
</tr>
<tr>
<td>glyphs</td>
<td>array</td>
<td>only if the parent’s format is glyphs</td>
</tr>
<tr>
<td>class</td>
<td>array</td>
<td>only if the parent’s format is class</td>
</tr>
<tr>
<td>coverage</td>
<td>array</td>
<td>only if the parent’s format is coverage</td>
</tr>
<tr>
<td>reversecoverage</td>
<td>array</td>
<td>only if the parent’s format is reversecoverage</td>
</tr>
</tbody>
</table>

A glyph table is:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>names</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>back</td>
<td>string</td>
<td></td>
</tr>
<tr>
<td>fore</td>
<td>string</td>
<td></td>
</tr>
</tbody>
</table>

A class table is:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>array</td>
<td>of numbers</td>
</tr>
<tr>
<td>before</td>
<td>array</td>
<td>of numbers</td>
</tr>
<tr>
<td>after</td>
<td>array</td>
<td>of numbers</td>
</tr>
</tbody>
</table>

coverage:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>array</td>
<td>of strings</td>
</tr>
<tr>
<td>before</td>
<td>array</td>
<td>of strings</td>
</tr>
<tr>
<td>after</td>
<td>array</td>
<td>of strings</td>
</tr>
</tbody>
</table>

reversecoverage:

<table>
<thead>
<tr>
<th>key</th>
<th>type</th>
<th>explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>current</td>
<td>array</td>
<td>of strings</td>
</tr>
<tr>
<td>before</td>
<td>array</td>
<td>of strings</td>
</tr>
<tr>
<td>after</td>
<td>array</td>
<td>of strings</td>
</tr>
<tr>
<td>replacements</td>
<td>string</td>
<td></td>
</tr>
</tbody>
</table>
12 The backend libraries

12.1 The pdf library

This library contains variables and functions that are related to the pdf backend. You can find more details about the expected values to setters in section 2.2.

12.1.1 mapfile, mapline

pdf.mapfile(<string> map file)
pdf.mapline(<string> map line)

These two functions can be used to replace primitives \pdfmapfile and \pdfmapline inherited from pdf\TeX. They expect a string as only parameter and have no return value. The first character in a map line can be -, + or = which means as much as remove, add or replace this line.

12.1.2 [set|get][catalog|info|names|trailer]

These functions complement the corresponding pdf backend token lists dealing with metadata. The value types are strings and they are written out to the pdf file directly after the token registers.

12.1.3 [set|get][pageattributes|pageresources|pagesattributes]

These functions complement the corresponding pdf backend token lists dealing with page resources. The variables have no interaction with the corresponding pdf backend token register. They are written out to the pdf file directly after the token registers.

12.1.4 [set|get][xformattributes|xformresources]

These functions complement the corresponding pdf backend token lists dealing with reuseable boxes and images. The variables have no interaction with the corresponding pdf backend token register. They are written out to the pdf file directly after the token registers.

12.1.5 getversion and [set|get]minorversion

The version is frozen in the binary but you can set the minor version. What minor version you set depends on what pdf features you use. This is out of control of Lua\TeX.

12.1.6 getcreationdate

This function returns a string with the date in the format that ends up in the pdf file, in this case it’s: D:20170215114838+01'00'.
12.1.7 [set|get]inclusionerrorlevel, [set|get]ignoreunknownimages

These variables control how errors in included images are treated. They are modeled after the `pdfTeX` equivalents.

12.1.8 [set|get]supressoptionalinfo

This bitset determines what kind of information gets flushed. By default, we flush all.

12.1.9 [set|get]trailerid

You can set your own trailer id. This has to be a valid array string with checksums.

12.1.10 [set|get]compresslevel

These two functions set the level of compression. The minimum value is 0, the maximum is 9.

12.1.11 [set|get]objcompresslevel

These two functions set the level of compression. The minimum value is 0, the maximum is 9.

12.1.12 [set|get]gentounicode

This flag enables unicode generation (like in `pdfTeX`).

12.1.13 [set|get]omitcidset

This flag disables inclusion of a so-called CIDSet which can be handy when aiming at some of the many PDF substandards.

12.1.14 [set|get]decimaldigits

These two functions set the accuracy of floats written to the PDF file. You can set any value but the backend will not go below 3 and above 6.

12.1.15 [set|get]pkresolution

These setter takes two arguments: the resolution and an optional zero or one that indicates if this is a fixed one. The getter returns these two values.

12.1.16 getlast[obj|link|annot] and getretval

These status variables are similar to the ones traditionally used in the backend interface at the `TeX` end.
12.1.17 maxobjnum and objtype, fontname, fontobjnum, fontsize, xformname

These (and some other) introspective helpers were moved from the the tex namespace to the pdf namespace but kept their original names. They are mostly used when you construct pdf objects yourself and need for instance information about a (to be) embedded font.

12.1.18 [set|get]origin

This one is used to set the horizontal and/or vertical offset, a traditional backend property.

```latex
pdf.setorigin() -- sets both to 0pt
pdf.setorigin(tex.sp("1in")) -- sets both to 1in
pdf.setorigin(tex.sp("1in"),tex.sp("1in"))
```

The counterpart of this function returns two values.

12.1.19 [set|get]imageresolution

These two functions relate to the imageresolution that is used when the image itself doesn’t provide a non-zero x or y resolution.

12.1.20 [set|get][link|dest|thread|xform]margin

These functions can be used to set and retrieve the margins that are added to the natural bounding boxes of the respective objects.

12.1.21 get[pos|hpos|vpos]

These function get current location on the output page, measured from its lower left corner. The values return scaled points as units.

```latex
local h, v = pdf.getpos()
```

12.1.22 [has|get]matrix

The current matrix transformation is available via the getmatrix command, which returns 6 values: sx, rx, ry, sy, tx, and ty. The hasmatrix function returns true when a matrix is applied.

```latex
if pdf.hasmatrix() then
    local sx, rx, ry, sy, tx, ty = pdf.getmatrix()
    -- do something useful or not
end
```
12.1.23 print

You can print string to the pdf document from within a within a \latex call. This function is not to be used inside \directlua unless you know exactly what you are doing.

\begin{verbatim}
pdf.print(<string> s)
pdf.print(<string> type, <string> s)
\end{verbatim}

The optional parameter can be used to mimic the behavior of pdf literals: the type is direct or page.

12.1.24 immediateobj

This function creates a pdf object and immediately writes it to the pdf file. It is modelled after pdfTeX's immediate \pdfobj primitives. All function variants return the object number of the newly generated object.

\begin{verbatim}
<number> n =
pdf.immediateobj(<string> objtext)
<number> n =
pdf.immediateobj("file", <string> filename)
<number> n =
pdf.immediateobj("stream", <string> streamtext, <string> attrtext)
<number> n =
pdf.immediateobj("streamfile", <string> filename, <string> attrtext)
\end{verbatim}

The first version puts the objtext raw into an object. Only the object wrapper is automatically generated, but any internal structure (like << >> dictionary markers) needs to provided by the user. The second version with keyword file as first argument puts the contents of the file with name filename raw into the object. The third version with keyword stream creates a stream object and puts the streamtext raw into the stream. The stream length is automatically calculated. The optional attrtext goes into the dictionary of that object. The fourth version with keyword streamfile does the same as the third one, it just reads the stream data raw from a file.

An optional first argument can be given to make the function use a previously reserved pdf object.

\begin{verbatim}
<number> n =
pdf.immediateobj(<integer> n, <string> objtext)
<number> n =
pdf.immediateobj(<integer> n, "file", <string> filename)
<number> n =
pdf.immediateobj(<integer> n, "stream", <string> streamtext, <string> attrtext)
<number> n =
pdf.immediateobj(<integer> n, "streamfile", <string> filename, <string> attrtext)
\end{verbatim}
12.1.25 obj

This function creates a pdf object, which is written to the pdf file only when referenced, e.g., by refobj().

All function variants return the object number of the newly generated object, and there are two separate calling modes. The first mode is modelled after pdfT\textsc{E}X's \texttt{pdfobj} primitive.

\begin{verbatim}
<number> n =
    pdf.obj(<string> objtext)
<number> n =
    pdf.obj("file", <string> filename)
<number> n =
    pdf.obj("stream", <string> streamtext, <string> attrtext)
<number> n =
    pdf.obj("streamfile", <string> filename, <string> attrtext)
\end{verbatim}

An optional first argument can be given to make the function use a previously reserved pdf object.

\begin{verbatim}
<number> n =
    pdf.obj(<integer> n, <string> objtext)
<number> n =
    pdf.obj(<integer> n, "file", <string> filename)
<number> n =
    pdf.obj(<integer> n, "stream", <string> streamtext, <string> attrtext)
<number> n =
    pdf.obj(<integer> n, "streamfile", <string> filename, <string> attrtext)
\end{verbatim}

The second mode accepts a single argument table with key–value pairs.

\begin{verbatim}
<number> n = pdf.obj {
    type = <string>,
    immediate = <boolean>,
    objnum = <number>,
    attr = <string>,
    compresslevel = <number>,
    objcompression = <boolean>,
    file = <string>,
    string = <string>
}
\end{verbatim}

The type field can have the values \texttt{raw} and \texttt{stream}, this field is required, the others are optional (within constraints).

Note: this mode makes obj look more flexible than it actually is: the constraints from the separate parameter version still apply, so for example you can't have both \texttt{string} and \texttt{file} at the same time.
12.1.26 refobj

This function, the Lua version of the \pdfrefobj primitive, references an object by its object number, so that the object will be written out.

pdf.refobj(<integer> n)

This function works in both the \directlua and \latexlua environment. Inside \directlua a new whatsit node 'pdf_refobj' is created, which will be marked for flushing during page output and the object is then written directly after the page, when also the resources objects are written out. Inside \latexlua the object will be marked for flushing.

This function has no return values.

12.1.27 reserveobj

This function creates an empty pdf object and returns its number.

<number> n = pdf.reserveobj()
<number> n = pdf.reserveobj("annot")

12.1.28 registerannot

This function adds an object number to the /Annots array for the current page without doing anything else. This function can only be used from within \latexlua.

pdf.registerannot (<number> objnum)

12.1.29 newcolorstack

This function allocates a new color stack and returns its id. The arguments are the same as for the similar backend extension primitive.

pdf.newcolorstack("0 g","page",true) -- page|direct|origin

12.1.30 setfontattributes

This function will force some additional code into the font resource. It can for instance be used to add a custom ToUnicode vector to a bitmap file.

pdf.setfontattributes(<number> font id, <string> pdf code)

12.2 The pdfscanner library

The pdfscanner library allows interpretation of pdf content streams and /ToUnicode (cmap) streams. You can get those streams from the epdf library, as explained in an earlier section. There is only a single top-level function in this library:
pdfscanner.scan (<Object> stream, <table> operatortable, <table> info)

The first argument, stream, should be either a pdf stream object, or a pdf array of pdf stream objects (those options comprise the possible return values of <Page>:getContents() and <Object>:getStream() in the epdf library).

The second argument, operatortable, should be a Lua table where the keys are pdf operator name strings and the values are Lua functions (defined by you) that are used to process those operators. The functions are called whenever the scanner finds one of these pdf operators in the content stream(s). The functions are called with two arguments: the scanner object itself, and the info table that was passed are the third argument to pdfscanner.scan.

Internally, pdfscanner.scan loops over the pdf operators in the stream(s), collecting operands on an internal stack until it finds a pdf operator. If that pdf operator's name exists in operatortable, then the associated function is executed. After the function has run (or when there is no function to execute) the internal operand stack is cleared in preparation for the next operator, and processing continues.

The scanner argument to the processing functions is needed because it offers various methods to get the actual operands from the internal operand stack.

A simple example of processing a pdf’s document stream could look like this:

```lua
function Do (scanner, info)
    local val = scanner:pop()
    local resources = info.resources
    local xobject = resources:lookup("XObject"):getDict():lookup(name)
    print (info.space ..'Use XObject '.. name)
    if xobject and xobject:isStream() then
        local dict = xobject:getStream():getDict()
        if dict then
            local name = dict:lookup("Subtype")
            if name:getName() == "Form" then
                local newinfo = {
                    space = info.space .. " " ,
                    resources = dict:lookup("Resources"):getDict()
                }
                pdfscanner.scan(xobject, operatortable, newinfo)
            end
        end
    end
end

operatortable = { Do = Do }

doc = epdf.open(arg[1])
pagenum = 1

while pagenum <= doc:getNumPages() do
```

The backend libraries 215
This example iterates over all the actual content in the pdf, and prints out the found XObject
names. While the code demonstrates quite some of the epdf functions, let’s focus on the type
pdfscanner specific code instead.

From the bottom up, the following line runs the scanner with the pdf page’s top-level content.

dfscanner.scan(page:getContents(), operatortable, info)

The third argument, info, contains two entries: space is used to indent the printed output, and
resources is needed so that embedded XForms can find their own content.

The second argument, operatortable defines a processing function for a single pdf operator, Do.

The function Do prints the name of the current XObject, and then starts a new scanner for that
object’s content stream, under the condition that the XObject is in fact a /Form. That nested
scanner is called with new info argument with an updated space value so that the indentation
of the output nicely nests, and with an new resources field to help the next iteration down to
properly process any other, embedded XObjects.

Of course, this is not a very useful example in practise, but for the purpose of demonstrating
dfscanner, it is just long enough. It makes use of only one scanner method: scanner:pop().
That function pops the top operand of the internal stack, and returns a Lua table where the
object at index one is a string representing the type of the operand, and object two is its value.

The list of possible operand types and associated Lua value types is:

integer  <number>
real     <number>
boolean  <boolean>
name     <string>
operator <string>
string   <string>
array    <table>
dict     <table>

In case of integer or real, the value is always a Lua (floating point) number.

In case of name, the leading slash is always stripped.

In case of string, please bear in mind that pdf actually supports different types of strings (with
different encodings) in different parts of the pdf document, so may need to reencode some of the
results; pdfscanner always outputs the byte stream without reencoding anything. pdfscanner
does not differentiate between literal strings and hexadecimal strings (the hexadecimal values
are decoded), and it treats the stream data for inline images as a string that is the single operand
for EI.

In case of array, the table content is a list of pop return values and in case of dict, the table
keys are pdf name strings and the values are pop return values.

There are few more methods defined that you can ask scanner:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>pop</td>
<td>as explained above</td>
</tr>
<tr>
<td>popNumber</td>
<td>return only the value of a real or integer</td>
</tr>
<tr>
<td>popName</td>
<td>return only the value of a name</td>
</tr>
<tr>
<td>popString</td>
<td>return only the value of a string</td>
</tr>
<tr>
<td>popArray</td>
<td>return only the value of an array</td>
</tr>
<tr>
<td>popDict</td>
<td>return only the value of a dict</td>
</tr>
<tr>
<td>popBool</td>
<td>return only the value of a boolean</td>
</tr>
<tr>
<td>done</td>
<td>abort further processing of this scan() call</td>
</tr>
</tbody>
</table>

The popXXX are convenience functions, and come in handy when you know the type of the
operands beforehand (which you usually do, in pdf). For example, the Do function could have
used local name = scanner:popName() instead, because the single operand to the Do operator
is always a pdf name object.

The done function allows you to abort processing of a stream once you have learned everything
you want to learn. This comes in handy while parsing /ToUnicode, because there usually is
trailing garbage that you are not interested in. Without done, processing only end at the end of
the stream, possibly wasting cpu cycles.

### 12.3 The epdf library

The epdf library provides Lua bindings to many pdf access functions that are defined by the
poppler pdf viewer library (written in C++ by Kristian Høgsberg, based on xpdf by Derek Noon-
burg). Within LuaT̆X xpdf functionality is being used since long time to embed pdf files. The
epdf library allows to scrutinize an external pdf file. It gives access to its document structure:
catalog, cross-reference table, individual pages, objects, annotations, info, and metadata. The
epdf library only provides read-only acess. At some point we might decide to limit the interface
to a reasonable subset.

For a start, a pdf file is opened by epdf.open() with file name, e.g.:

```lua
doc = epdf.open("foo.pdf")
```

This normally returns a PDFDoc userdata variable; but if the file could not be opened successfully,
instead of a fatal error just the value nil is returned.

All Lua functions in the epdf library are named after the poppler functions listed in the poppler
header files for the various classes, e.g., files PDFDoc.h, Dict.h, and Array.h. These files can
be found in the poppler subdirectory within the LuaT̆X sources. Which functions are already
implemented in the epdf library can be found in the Lua\TeX source file lepdflib.cc. For using the epdf library, knowledge of the pdf file architecture is indispensable.

There are many different userdata types defined by the epdf library, currently these are AnnotBorderStyle, AnnotBorder, Annots, Annot, Array, Attribute, Catalog, Dict, EmbFile, GString, LinkDest, Links, Link, ObjectStream, Object, PDFDoc, PDFRectangle, Page, Ref, Stream, StructElement, StructTreeRoot, TextSpan, XRefEntry and XRef.

All these userdata names and the Lua access functions closely resemble the classes naming from the poppler header files, including the choice of mixed upper and lower case letters. The Lua function calls use object-oriented syntax, e.g., the following calls return the Page object for page 1:

\begin{verbatim}
  pageref = doc:getCatalog():getPageRef(1)
  pageobj = doc:getXRef():fetch(pageref.num, pageref.gen)
\end{verbatim}

But writing such chained calls is risky, as an intermediate function may return nil on error. Therefore between function calls there should be Lua type checks (e.g., against nil) done. If a non-object item is requested (for instance a Dict item by calling page:getPieceInfo(), cf. Page.h) but not available, the Lua functions return nil (without error). If a function should return an Object, but it’s not existing, a Null object is returned instead, also without error. This is in-line with poppler behavior.

All library objects have a \_gc metamethod for garbage collection. The \_tostring metamethod gives the type name for each object.

These are the object constructors:

\begin{verbatim}
<PDFDoc>  = epdf.open(<string> PDF filename)
<Annot>   = epdf.Annot(<XRef>, <Dict>, <Catalog>, <Ref>)
<Annots>  = epdf.Annots(<XRef>, <Catalog>, <Object>)
<Array>   = epdf.Array(<XRef>)
<Attribute> = epdf.Attribute(<Type>,<Object>)| epdf.Attribute(<string>, <int>, <Object>)
<Dict>    = epdf.Dict(<XRef>)
<Object>  = epdf.Object()
<PDFRectangle> = epdf.PDFRectangle()
\end{verbatim}

The functions StructElement_Type, Attribute_Type and AttributeOwner_Type return a hash table \{<string>,<integer>\}.

Annot methods:

\begin{verbatim}
<boolean> = <Annot>:isOk()
<Object>  = <Annot>:getAppearance()
<AnnotBorder> = <Annot>:getBorder()
<boolean> = <Annot>:match(<Ref>)
\end{verbatim}

AnnotBorderStyle methods:

\begin{verbatim}
<number>  = <AnnotBorderStyle>:getWidth()
\end{verbatim}
Annots methods:

<integer> = <Annots>:getNumAnnots()
<Annot> = <Annots>:getAnnot(<integer>)

Array methods:

<Array>:incRef()
<Array>:decRef()
<integer> = <Array>:getLength()
<Array>:add(<Object>)
<Object> = <Array>:get(<integer>)
<Object> = <Array>:getNF(<integer>)
<string> = <Array>:getString(<integer>)

Attribute methods:

<boolean> = <Attribute>:isOk()
<integer> = <Attribute>:getType()
<integer> = <Attribute>:getOwner()
<string> = <Attribute>:getTypeName()
<string> = <Attribute>:getOwnerName()
<Object> = <Attribute>:getValue()
<Object> = <Attribute>:getDefaultValue
<string> = <Attribute>:getName()
<integer> = <Attribute>:getRevision()
    <Attribute>:setRevision(<unsigned integer>)
<boolean> = <Attribute>:istHidden()
    <Attribute>:setHidden(<boolean>)
<string> = <Attribute>:getFormattedValue()
<string> = <Attribute>:setFormattedValue(<string>)

Catalog methods:

<boolean> = <Catalog>:isOK()
<integer> = <Catalog>:getNumPages()
<Object> = <Catalog>:getPage(<integer>)
<Ref> = <Catalog>:getPageRef(<integer>)
<string> = <Catalog>:getBaseURI()
<string> = <Catalog>:readMetadata()
<Object> = <Catalog>:getStructTreeRoot()
<integer> = <Catalog>:findPage(<integer> object number, <integer> object generation)
<LinkDest> = <Catalog>:findDest(<string> name)
<Object> = <Catalog>:getDests()
<integer> = <Catalog>:numEmbeddedFiles()
<EmbFile> = <Catalog>:embeddedFile(<integer>)
<integer> = <Catalog>:numJS()
<string> = <Catalog>:getJS(<integer>)
<Object> = <Catalog>:getOutline()
<Object> = <Catalog>:getAcroForm()

EmbFile methods:
<string> = <EmbFile>:name()
<string> = <EmbFile>:description()
<Integer> = <EmbFile>:size()
<string> = <EmbFile>:modDate()
<string> = <EmbFile>:createDate()
<string> = <EmbFile>:checksum()
<string> = <EmbFile>:mimeType()
<Object> = <EmbFile>:streamObject()
<boolean> = <EmbFile>:isOk()

Dict methods:

<boolean> = <Dict>:isOK()
<object> = <Dict>:lookup(<string>)
<Object> = <Dict>:lookupNF(<string>)
<Integer> = <Dict>:lookupInt(<string>, <string>)
<string> = <Dict>:getKey(<integer>)
<Object> = <Dict>:getVal(<integer>)
<Object> = <Dict>:getValNF(<integer>)
<boolean> = <Dict>:hasKey(<string>)

Link methods:
<boolean> = <Link>:isOK()
<boolean> = <Link>:inRect(<number>, <number>)

LinkDest methods:
<boolean> = <LinkDest>:isOK()
<Integer> = <LinkDest>:getKind()
<string> = <LinkDest>:getKindName()
<boolean> = <LinkDest>:isPageRef()
<Integer> = <LinkDest>:getPageNum()
<Ref> = <LinkDest>:getPageRef()
<number> = <LinkDest>:getLeft()
<number> = <LinkDest>:getBottom()
<number> = <LinkDest>:getRight()
<number>  = <LinkDest>:getTop()
<number>  = <LinkDest>:getZoom()
<boolean> = <LinkDest>:getChangeLeft()
<boolean> = <LinkDest>:getChangeTop()
<boolean> = <LinkDest>:getChangeZoom()

Links methods:
<integer>  = <Links>:getNumLinks()
<Link>     = <Links>:getLink(<integer>)

Object methods:
<Object>:initBool(<boolean>)
<Object>:initInt(<integer>)
<Object>:initReal(<number>)
<Object>:initString(<string>)
<Object>:initName(<string>)
<Object>:initNull()
<Object>:initArray(<XRef>)
<Object>:initDict(<XRef>)
<Object>:initStream(<Stream>)
<Object>:initRef(<integer> object number, <integer> object generation)
<Object>:initCmd(<string>)
<Object>:initError()
<Object>:initEOF()
<integer>  = <Object>:fetch(<XRef>)
<integer>  = <Object>:getType()
<string>   = <Object>:getTypeName()
<boolean>  = <Object>:isBool()
<boolean>  = <Object>:isInt()
<boolean>  = <Object>:isReal()
<boolean>  = <Object>:isNum()
<boolean>  = <Object>:isString()
<boolean>  = <Object>:isName()
<boolean>  = <Object>:isNull()
<boolean>  = <Object>:isArray()
<boolean>  = <Object>:isDict()
<boolean>  = <Object>:isStream()
<boolean>  = <Object>:isRef()
<boolean>  = <Object>:isCmd()
<boolean>  = <Object>:isError()
<boolean>  = <Object>:isEOF()
<boolean>  = <Object>:isNone()
<boolean>  = <Object>:getBool()
<integer>  = <Object>:getInt()
<number>   = <Object>:getReal()
<number> = <Object>:getNum()
<string> = <Object>:getString()
<string> = <Object>:getName()
<Array> = <Object>:getArray()
<Dict> = <Object>:getDict()
AsStream> = <Object>:getStream()
<Ref> = <Object>:getRef()
<integer> = <Object>:getRefNum()
<integer> = <Object>:getRefGen()
<string> = <Object>:getCmd()
<integer> = <Object>:arrayGetLength()
    = <Object>:arrayAdd(<Object>)
<Object> = <Object>:arrayGet(<integer>)
<Object> = <Object>:arrayGetNF(<integer>)
<integer> = <Object>:dictGetLength(<integer>)
    = <Object>:dictAdd(<string>, <Object>)
    = <Object>:dictSet(<string>, <Object>)
<Object> = <Object>:dictLookup(<string>)
<Object> = <Object>:dictLookupNF(<string>)
<string> = <Object>:dictgetKey(<integer>)
<Object> = <Object>:dictgetVal(<integer>)
<Object> = <Object>:dictgetValNF(<integer>)
<boolean> = <Object>:streamIs(<string>)
    = <Object>:streamReset()
<integer> = <Object>:streamGetChar()
<integer> = <Object>:streamLookChar()
<integer> = <Object>:streamGetPos()
<Object> = <Object>:streamSetPos(<integer>)
<Dict> = <Object>:streamGetDict()

Page methods:
<boolean> = <Page>:isOk()
<integer> = <Page>:getNum()
<PDFRectangle> = <Page>:getMediaBox()
<PDFRectangle> = <Page>:getCropBox()
<boolean> = <Page>:isCropped()
<number> = <Page>:getMediaWidth()
<number> = <Page>:getMediaHeight()
<number> = <Page>:getCropWidth()
<number> = <Page>:getCropHeight()
<PDFRectangle> = <Page>:getBleedBox()
<PDFRectangle> = <Page>:getTrimBox()
<PDFRectangle> = <Page>:getArtBox()
<integer> = <Page>:getRotate()
<string> = <Page>:getLastModified()
<Dict> = <Page>:getBoxColorInfo()
<Dict> = <Page>:getGroup()
<Stream> = <Page>:getMetadata()
<Dict> = <Page>:getPieceInfo()
<Dict> = <Page>:getSeparationInfo()
<Dict> = <Page>:getResourceDict()
<Object> = <Page>:getAnnots()
<Links> = <Page>:getLinks(<Catalog>)
<Object> = <Page>:getContents()

PDFDoc methods:

<boolean> = <PDFDoc>:isOk()
<integer> = <PDFDoc>:getErrorCode()
<string> = <PDFDoc>:getErrorCodeName()
<string> = <PDFDoc>:getFileName()
<XRef> = <PDFDoc>:getXRef()
<Catalog> = <PDFDoc>:getCatalog()
<number> = <PDFDoc>:getPageMediaWidth()
<number> = <PDFDoc>:getPageMediaHeight()
<number> = <PDFDoc>:getPageCropWidth()
<number> = <PDFDoc>:getPageCropHeight()
<integer> = <PDFDoc>:getNumPages()
<string> = <PDFDoc>:readMetadata()
<Object> = <PDFDoc>:getStructTreeRoot()
<integer> = <PDFDoc>:findPage(<integer> object number, <integer> object generation)
<Links> = <PDFDoc>:getLinks(<integer>)
<LinkDest> = <PDFDoc>:findDest(<string>)
<boolean> = <PDFDoc>:isEncrypted()
<boolean> = <PDFDoc>:okToPrint()
<boolean> = <PDFDoc>:okToChange()
<boolean> = <PDFDoc>:okToCopy()
<boolean> = <PDFDoc>:okToAddNotes()
<boolean> = <PDFDoc>:isLinearized()
<Object> = <PDFDoc>:getDocInfo()
<Object> = <PDFDoc>:getDocInfoNF()
<integer> = <PDFDoc>:getPDFMajorVersion()
<integer> = <PDFDoc>:getPDFMinorVersion()

PDFRectangle methods:

<boolean> = <PDFRectangle>:isValid()

Stream methods:

<integer> = <Stream>:getKind()
<string> = <Stream>:getKindName()
 = <Stream>:reset()
= <Stream>::close()
<integer> = <Stream>::getChar()
<integer> = <Stream>::lookChar()
<integer> = <Stream>::getRawChar()
<integer> = <Stream>::getUnfilteredChar()
<integer> = <Stream>::unfilteredReset()
<integer> = <Stream>::getPos()
<boolean> = <Stream>::isBinary()
<Stream> = <Stream>::getUndecodedStream()
<Dict> = <Stream>::getDict()

StructElement methods:
<string> = <StructElement>::getTypeName()
<integer> = <StructElement>::getType()
<boolean> = <StructElement>::isOk()
<boolean> = <StructElement>::isBlock()
<boolean> = <StructElement>::isInline()
<boolean> = <StructElement>::isGrouping()
<boolean> = <StructElement>::isContent()
<boolean> = <StructElement>::isObjectRef()
<integer> = <StructElement>::getMCID()
<Ref> = <StructElement>::getObjectRef()
<Ref> = <StructElement>::getParentRef()
<boolean> = <StructElement>::hasPageRef()
<Ref> = <StructElement>::getPageRef()
<StructTreeRoot> = <StructElement>::getStructTreeRoot()
<string> = <StructElement>::getID()
<string> = <StructElement>::getLanguage()
<integer> = <StructElement>::getRevision()
<StructElement>::setRevision(<unsigned integer>)
<string> = <StructElement>::getTitle()
<string> = <StructElement>::getExpandedAbbr()
<integer> = <StructElement>::getNumChildren()
<StructElement> = <StructElement>::getChild()
<integer> = <StructElement>::getNumAttributes()
<Attribute> = <StructElement>::getAttribute(<integer>)
<string> = <StructElement>::appendAttribute(<Attribute>)
<Attribute> = <StructElement>::findAttribute(<Attribute::Type>,boolean,Attribute::Owner)
<string> = <StructElement>::getAltText()
<string> = <StructElement>::getActualText()
<string> = <StructElement>::getText(<boolean>)
<table> = <StructElement>::getTextSpans()

StructTreeRoot methods:
TextSpan han only one method:

<string> = <TestSpan>:getText()

XRef methods:

<boolean> = <XRef>:isOk()
<integer> = <XRef>:getErrorCode()
<boolean> = <XRef>:isEncrypted()
<boolean> = <XRef>:okToPrint()
<boolean> = <XRef>:okToPrintHighRes()
<boolean> = <XRef>:okToChange()
<boolean> = <XRef>:okToCopy()
<boolean> = <XRef>:okToAddNotes()
<boolean> = <XRef>:okToFileForm()
<boolean> = <XRef>:okToAccessibility()
<boolean> = <XRef>:okToAssemble()
<Object> = <XRef>:getCatalog()
<Object> = <XRef>:fetch(<integer> object number, <integer> object generation)
<Object> = <XRef>:getDocInfo()
<Object> = <XRef>:getDocInfoNF()
<integer> = <XRef>:getNumObjects()
<integer> = <XRef>:getRootNum()
<integer> = <XRef>:getRootGen()
<integer> = <XRef>:getSize()
<Object> = <XRef>:getTrailerDict()

There is an experimental function epdf.openMemStream that takes three arguments:

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
name this is a unique identifier that is used for hashing the stream, so that multiple doesn’t use more memory

Instead of a light userdata stream you can also pass a Lua string, in which case the given length is (at most) the string length.

The function returns a epdf 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.