The Components of \TeX

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Abstract
\TeX \ needs \ a \ great \ amount \ of \ supplementary \ components \ (files \ and \ programs) \ of \ which \ the \ meaning \ and \ interaction \ often \ is \ unknown. \ This \ paper \ explains \ the \ components \ of \ the \ kernel \ system \ \TeX \ that \ are \ visible \ for \ the \ \TeX \ user \ and \ their \ relations.

1 About this Report
\TeX \ is \ a \ typesetting \ system \ which \ offers \ authors \ easy \ usage \ of \ powerful \ typesetting \ features \ to \ produce \ printed \ matter \ which \ is \ the \ state \ of \ the \ art \ of \ computer \ typesetting. \ This \ is, \ however, \ not \ done \ by \ the \ \TeX \ program \ alone: \ A \ significant \ number \ of \ supplementary \ programs \ and \ files \ together \ form \ the \ complete \ typesetting \ and \ authoring \ system. \ Along \ with \ the \ programs \ that \ belong \ to \ \TeX \ directly, \ there \ exist \ two \ other \ major \ programs \ which \ were \ built \ by \ DONALD \ KNUTH \ in \ connection \ with \ \TeX \ and \ must \ be \ included \ in \ an \ explanation \ of \ the \ full \ system: \ METAFONT, \ for \ the \ generation \ of \ fonts, \ and \ WEB, \ a \ documentation \ and \ developing \ ‘language’ \ for \ programming. \ \TeX \ and \ METAFONT \ are \ written \ in \ WEB.

This \ text \ describes \ this \ ‘kernel’ \ \TeX \ from \ a \ user’s \ viewpoint: \ at \ the \ end \ you \ should \ have \ an \ overview \ of \ the \ ingredients \ of \ the \ \TeX \ system, \ and \ about \ the \ files \ and \ support \ programs \ that \ are \ essential \ for \ you \ as \ a \ user. \ This \ will \ not, \ however, \ be \ an \ introduction \ to \ the \ capabilities \ of \ \TeX \ or \ how \ you \ may \ run \ \TeX \ on \ your \ computer.

I \ will \ use \ marginal \ notes \ to \ identify \ the \ places \ where \ terms \ are \ explained \ for \ the \ first \ time. \ Abbreviations \ for \ file \ types \ — \ usually \ identified \ by \ common \ suffixes \ or \ extensions \ — \ are \ set \ in \ a \ monospace \ type \ ("typewriter") \ and \ those

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abbreviations are put into the margin, too. Please note that these abbreviations are sometimes not identical with the file extensions (see also Table 1).

This report is the start of a series that describes the subsystems mentioned above and their respective components. In that series each report will focus on one subsystem in a special point of view; it should not result in gigantic descriptions which tell everything (and then nothing). In my opinion the following reports will be of interest:

- the structure of a standard installation of \TeX
- \TeX\ DVI drivers and fonts
- possibilities of graphics inclusion in \TeX\ documents
- the components of \METAfont
- the structure of a standard installation of \METAfont
- \WEB\ systems — the concept of Literate Programming
- other (though not yet planned) themes of interest are perhaps
  - differences between \TeX\ and DTP systems
  - the way how \TeX\ works (there exists some good books on this topic!)
  - the limits of \TeX
  - \TeX\ as a programming language

The reports will be published in this sequence.

2 What is \TeX?  

\TeX\ is a typesetting system with great power for the typesetting of formulae. Its basic principle is that structures in the document are marked and transformed into typeset output. Providing such information about the structure of a document is known as \markup. If the marks describe the look of the document, it is called \optical markup, while, if document structures are marked, it is called \logical markup. \TeX\ provides both forms of markup, i.e., exact control of the layout of parts of the document and their positioning as well as the markup of the structure of formulae or document components. The logical markup is mapped to the optical one by \TeX\ so that layout may serve for the identification of structures by the reader.¹

The kernel of the \TeX\ typesetting system is the formatting program \TeX82, typesetting machine \TeX82

¹Layout – and book design in general – do not represent useless beauty. A good book design must first support the understanding of the content to produce readable text. So it is \textit{aesthetic} in its best sense, since it connects form and contents and builds a new quality.
which is often simply called \TeX. This usage shall be adopted here whenever
the difference between the complete system and the formatter is unimportant
or obvious. \TeX82 is a big monolithic program which is published in the book
\TeX: The Program byDonaldKnuth. Its features may be separated into two
levels:

1. \TeX82 formats text, i.e., it breaks it into paragraphs (including automatic
hyphenation) and produces page breaks.

2. It provides the programming language \TeX which incorporates a macro
mechanism. This allows new commands to be built to support markup
at a higher level. DonaldKnuth presents an example in the \TeXbook:
Plain \TeX. A collection of macros which supports a special task and has
(hopefully) a common philosophy of usage is called a macro package.

High level features for optical markup, as represented by Plain \TeX, allow one
to build additional levels leading to full logical markup. At the moment, two
macro packages for logical markup are widespread: \AMS-\TeX and \LaTeX. Both
systems are built on top of Plain \TeX in addition to logical markup if
desired. This results in the effect that the author can use a mixture of structural
information and explicit layout information – a situation with a high potency of
features that nevertheless can (and does) lead to a lot of typographic nonsense!

As \TeX82 was built only for typesetting texts and to allow the realization
of new markup structures, many features are lacking which are required by
authors. To provide features like the production of an index or a bibliography
or the inclusion of graphics, additional programs have been written, which use
information from a \TeX82 formatting run, process them, and provide them for
the next \TeX82 run. Two supplementary programs are in widespread use and
available for many computer/operating system combinations: Bib\TeX, for the
production of a bibliography from a reference collection, and MakeIndex, for
the production of an index.

A special case of the processing of information provided by a \TeX run is the
production of a table of contents or the usage of cross references in a text. For
this only informations about page numbers, section numbers, etc., are needed.
These are provided by \TeX82 and can be processed by \TeX itself, so \TeX82
is used as its own post processor in this situation.

We have now seen that the \TeX typesetting system is a collection of tools
that consists of the typesetting engine \TeX82, macro packages (maybe several
that are based on others) and supplementary programs, used together with these
macro packages. This relation is illustrated by Figure 1.
3 Formatting

The formatting process of \TeX needs information about the dimensions of characters used for the paragraph breaking. A set of characters is grouped in *fonts*. (But this is a simplification as the notion “font” should be used for the realization of a type in a fixed size for a specific output device.) The dimensions of the characters of a font are called *font metrics*.

The format in which the font metrics are used by \TeX was defined by DONALD KNUTH and is called \texttt{TFM} format (“\TeX font metrics”). In this format, every character is described as a box with a height, a depth, and a width. \TeX only needs these measurements, it is not interested in the shape of the character. It is even possible that the character may extend outside the box, which may result in an overlap with other characters. The character measures are specified in a device independent dimension because \TeX processes its breaking algorithm independent of any output device.

During paragraph breaking, \TeX hyphenates automatically, which can be done in an almost language-independent way. For the adaption to different languages, *hyphenation patterns* are needed to parametrize the hyphenation algorithm.

The result of a \TeX formatting run is a \texttt{DVI} document, in which the type and position on the page are specified for each character to be output. The resolution that is used is so small that every possible output device will have a
coarser raster, so that the positioning is effectively device independent. The DVI document specifies only types, not the fonts themselves, so that the name DVI\(^2\) ("device independent") is accurate. To make the result of the formatting run available, the DVI file must be output by a so-called DVI driver on the desired output device.

If problems occur during the formatting, error messages or warnings are output on the terminal. Every message that appears on the terminal will also be written into a protocol file named LOG file. In this LOG file additional information may be placed that would have been too verbose for the output to the terminal. If this is the case, \TeX will tell the user so at the end of the formatting run. The messages of \TeX are not built in the program, they are stored in a (string) POOL file. These messages must be read in at the beginning of a run.

4 Macro Packages

The basic macro package is Plain \TeX, developed by Donald Knuth together with \TeX82. It parametrizes the \TeX82 typesetting machine so that it can typeset English texts with the Computer Modern type family. Additionally, Plain \TeX provides optical markup features. Plain \TeX is available as one source file, plain.tex. All other macro packages known to the author are based on Plain \TeX, i.e., they contain the source file plain.tex either originally or with modifications of less important parts. Next to Plain \TeX, the most important (free) available macro packages are \AMS-\TeX by Michael Spivak and \LaTeX by Leslie Lamport. Other free macro packages are often of only local importance (e.g. Blue\TeX, TEXT1, or \TeXsis) or are used in very special environments only (e.g. texinfo in the GNU project or webmac for WEB). Important commercial macro packages are Macro\TeX by Amy Hendrickson and \AMS-\TeX, also written by Michael Spivak.

These macro packages usually consist of a kernel that provides additional markup primitives. With such primitives, document styles can be built which realize logical markups by a corresponding layout. This layout can often be varied by sub-styles or style options which may also provide additional markups.

The macro packages produce supplementary files which contain information about the page breaks or the document markup. This information may be used by support programs – e.g., the specification of a reference from a bibliography database or the specification of an index entry with corresponding page number for the construction of an index. A special case is the information about cross references and headings for the building of a table of contents, as this information can be gathered and reused by \TeX directly.

\Slie\TeX is a special component of \LaTeX for the preparation of slides with

\footnote{This name is a problem because “DVI” is a trademark of Intel Corp. now, but the name DVI for \TeX output files pre-dates this.}
overlays. In TUGBoat volume 10, no. 3 (1989) \AMS-\TeX was announced, which will provide the functionality of \LaTeX within \AMS-\TeX. Macro\TeX is a toolbox of macro “modules” which may be used to realize new markups but, as it became available only short time ago, it is not yet widespread.

For the usage of these (and other) macro packages, one must check whether they need additional fonts which do not belong to the Computer Modern type family. For \LaTeX, e.g., fonts with additional symbols and with invisible characters (for the slide overlays) are needed, while \AMS-\TeX needs several additional font sets with mathematical and Cyrillic characters.

5 Support Programs

Only two support programs will be discussed here: \Bib\TeX by Oren Patashnik for the preparation of bibliographies and \MakeIndex by Pehong Chen and Michael Harrison for the preparation of a sorted index. For both tasks exist other, functionally equivalent, support programs. But the abovementioned are available on many operating systems, and have an “official” state as they are Leslie Lamport encourages their usage with \LaTeX in his documentation, and the TUG supports them for general use.

There is no totally portable mechanism for the inclusion of general graphics in \TeX documents, so that there are no machine independent support programs available.

\Bib\TeX is used to handle references collected in \BIB files. \TeX produces supplementary files which contain information about the required references, and \Bib\TeX generates from them a sorted bibliography in a \BBL file which may be subsequently used by \TeX. The kind of sorting and the type of cite keys are defined by bibliography styles, specified in \BST files. The messages of a \Bib\TeX run are written to a \BLG logfile.

\MakeIndex reads an \IDX support file that contains the index entries and the according page numbers, sorts these items, unifies them and writes them as \TeX input in an \IND file. The formatting style may be specified by an index style. The messages of a \MakeIndex run are written to a \ILG file.

6 Performance Improvements

Much of the work that \TeX\82 has to do is the same for every document:

1. All text has to be broken into lines. Text pieces in the same language are hyphenated with the same hyphenation patterns.
2. The basic markups of the corresponding macro packages must be available.
3. The required font metrics are much alike for many documents, as the font set used usually doesn’t differ that much.
To improve \TeX’s performance, hyphenation, markup, and font metrics descriptions are converted from an external, for (1) and (2) textual, representation into an internal representation which can easily be used by \TeX82. It is sensible to do this transformation only once, not for every document. The internal representation is stored in a FMT file. The storing is done with the \TeX command \texttt{\textbackslash dump}, so that FMT files often are called “dumped formats.” A FMT file can be read at the beginning of a \TeX82 run and is thus available for the processing of the actual text.

As the creation of a FMT file is done infrequently – usually for the update of a macro package – the formatting of texts can be done with a reduced version of the \TeX82 program that doesn’t contain the storage and the program parts for the transformation of the hyphenation patterns and for the dumping. The complete version of \TeX82 is needed in an initialization phase only and therefore called INIT\TeX. Additional improvements of the performance can be reached by the usage of production versions of \TeX82 from which parts for statistical analysis and for debugging are stripped.

\TeX versions that have no dumped formats preloaded, have the ability to load a dumped format (i.e. a FMT file), and have no ability to dump a FMT file (i.e., they are not INIT\TeX) are often called Vir\TeX, which stands for virgin \TeX.

7 Connections Between File Types and Components

In the above sections, the components of the \TeX authoring system were described, and the files that are read or written by these components mentioned. The connections between them all is demonstrated graphically in Figure 2. In this graphic, file types are represented by rectangles, and programs by ovals. The arrows mean “is read by” or “is produced by.” The abbreviations of the file types are explained in Table 1, which also lists the file identifications (suffixes or extensions) that these files usually have (but note that other file identifications are also in use).

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Figure 2: The Connection of Components and File Types
<table>
<thead>
<tr>
<th>File Type</th>
<th>Explanation</th>
<th>File Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEX</td>
<td>Text input</td>
<td>tex, ltx</td>
</tr>
<tr>
<td>DVI</td>
<td>\TeX82 output, formatted text</td>
<td>dvi</td>
</tr>
<tr>
<td>LOG</td>
<td>\TeX82 log file</td>
<td>log, lis, list</td>
</tr>
<tr>
<td>HYP</td>
<td>Hyphenation patterns</td>
<td>tex</td>
</tr>
<tr>
<td>TFM</td>
<td>Font metrics</td>
<td>tfm</td>
</tr>
<tr>
<td>POOL</td>
<td>String pool</td>
<td>pool, poo, pol</td>
</tr>
<tr>
<td>FMT</td>
<td>Format file</td>
<td>fmt</td>
</tr>
<tr>
<td>MAC</td>
<td>\TeX macro file</td>
<td>tex, doc</td>
</tr>
<tr>
<td>STY</td>
<td>\TeX style file</td>
<td>sty, tex, st, doc</td>
</tr>
<tr>
<td>AUX</td>
<td>Support files</td>
<td>aux, toc, lot, lof, glo, tmp, tex</td>
</tr>
<tr>
<td>BIB</td>
<td>Reference collections</td>
<td>bib</td>
</tr>
<tr>
<td>BBL</td>
<td>References or bibliographies</td>
<td>bbl</td>
</tr>
<tr>
<td>BLG</td>
<td>Bib\TeX log file</td>
<td>blg</td>
</tr>
<tr>
<td>BST</td>
<td>Bib\TeX style file</td>
<td>bst</td>
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<td>IND</td>
<td>Sorted index</td>
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<tr>
<td>IST</td>
<td>Index markup specification</td>
<td></td>
</tr>
<tr>
<td>ILG</td>
<td>\MakeIndex log file</td>
<td>ilg</td>
</tr>
</tbody>
</table>

Table 1: File Types