Sorting in BLUe

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Abstract

Macros for number and lexicographic sorting are supplied. Data can originate from the copy, from file, or generated automatically. Lexicographic sorting allows words with ligatures and diacritical marks. Applications treated are: sorting with respect to report generation with TEX as a database tool, sorting and compressing `index.tex`, Knuth's index reminders file, and sorting control sequences separately.
It is illustrated by various examples that a set can be sorted within TEX once the ordering of the set is defined and encoded in a comparison macro, in compliance with the parameter macro `\cmp`.

Keywords: Sorting, index preparation, database handling, multiple sorting keys, macro writing, education.

Introduction

Sorting is a fundamental process. With respect to TEX, sorting was needed by Amy Hendrickson for sorting address labels [15], by Alan Jeffreys [16] and by Lincoln Durst [9] for sorting index items, to name but a few. Donald Arseneau, Ian Green, Ronald Kappert [19], and myself [25], have used sorting within TEX for citation lists. For aspects with respect to index generation see [8] and [31]. Available is Makeindex [6], [27], to cooperate with LATEX, and Salomon's plain TEX version of it [33].

All the sorting with respect to index items are external, outside of TEX.[1] This is practical, but sorting within plain is possible.[2] An advantage of TEX is that it allows for abstraction with respect to the kind of data.

Normally, number sorting and lexicographic sorting are done by different routines. This is necessary because the exchange and comparison are generally tied up with the data type. Within TEX the exchange is independent of the type, and the relational operator can be used as parameter by the sorting macro. Furthermore, secondary (and more) keys can be accounted for. The latter facility is not always available in the external sorters.

The efficiency of a sorting process depends upon the character of the data. A nearly sorted list, or a small number of items, can be handled effectively by a linear sorting routine. A non-increasing sorted list can better be walked through in reverse order than sorted. In general sorters of complexity $O(n \log n)$ are efficient for random data. Quick sort comes in handy when only part of an array has to be sorted.

For a discussion of the wide area of sorting and searching, see [20], and for programming templates, see [37].[3] For the Dutch speaking community there is the nice introduction [2].

The challenge is to encode $O(n \log n)$ sorting algorithms in TEX in a simple but flexible way.[4] Issues to address are

- a data structure must be chosen
- macros to fill the data structure
- abstracting from the sorting algorithm—heap sort, quick sort, ...
- parameterizing the comparison and exchange operations,
- abstracting in lexicographic sorting from the ASCII[5] ordering, and the
- handling of ligatures and diacritical marks.

In the first section the printing of sequences is treated. The storing of the data is considered in the second section. The sorting is elaborated on in the sections 3 and 4: sorting of numbers, respectively lexicographic sorting

[1] However, citations lists are sorted within TEX.

[2] If not for the encoding challenge.

[3] Any sorting macro should implement the algorithm with the comparison and exchange operator as parameters.

[4] Compatibility of number and lexicographic sorting has been strived after, where the particular sorting variant can be realized by appropriate `\let`-equals of the parameters.

[5] ASCII is the abbreviation of American Standard Code for Information Interchange. An ASCII table—associating each character with a number—is provided in the TEXbook, p. 367.

in the presence of the Dutch ij-ligature and diacritical marks.[6] In the fifth section the applications: sorting address labels, sorting and compressing Knuth's index reminders file, and sorting of control sequences separately, are dealt with. In the appendices I supplied the listings of the files: `heap.tex`, `quick.tex`, `sort.tex` and my testdriver `sort.tst`.

There are so many details in sorting and the TEX encoding of it, that I hope that the remainder is not too concise for those who are really interested in the details of the TEX encoding. On the other hand, I hope it won't contain too much for those who just like to get an idea of the possibilities of TEX with respect to sorting.[7]

Approach. The three processes: initialization, sorting and typesetting, are separately and independently designed.

For filling the data structure I considered it handy to have a few macros which store from

- copy (`\seq`...`\qes`),
- a file (`\storefrom`), or
- a process, which (randomly) generate elements (`\storerandomn`, `\storerandomw`).

For sorting I provided

- the Ben Lee User level macros (`\sortn`, `\sortaw`, `\sortw`), and
- the blue collar macros (`\heapsort`, `\quicksort`).

For typesetting the data structure I used the macros `\prtn`, respectively `\prtw`.[8]

Files. The file `sort.tex` contains the macros for storing (`\seq`...`\qes`, `\storefrom`, and `\storerandomn`, `\storerandomw`), for sorting (`\sortn`, `\sortaw`, `\sortw`), and for typesetting (`\prtn`, `\prtw`, and `\prtind`). Apart from these, the file contains the common definitions of the `\heapsort` and `\quicksort` macros, as well as variants for the parameter macros.

The files `heap.tex` and `quick.tex` contain the `\heapsort`, respectively `\quicksort`, macro along with specific auxiliaries.

My testdriver is the file `sort.tst`.

Definitions and notations. A sequence is defined as a row of numbers, respectively words, separated by spaces. The structure `\csname`$\langle k\rangle$`\endcsname`, is associated with an array with index $k = 1, 2, \ldots, n$. To denote in the documentation a value pointed by the number $\langle k\rangle$, I made use of `\val`$\{\langle k\rangle\}$, with `\def\val#1{\csname#1\endcsname}`. Macro names take suffix -n, -w, when specific for number, respectively word data. For example `\sortn` stands for sort numbers, `\prtw` stands for print words. I have typeset the in-line results of the examples in bold face.

For transferring values to a macro, I generally refrained from the (optional) parameter mechanism, as it is used in nowadays high-level programming languages. Instead I used Knuth's parameter TEXnique, which comes down to providing definitions and using these by invokations, eventually after a `\let`-equal.

I have used the shorthand notation `\ea`, `\nx`, and `\ag` for `\expandafter`, `\noexpand`, respectively `\aftergroup`. `\k` is used as counter to loop through the values $1, 2, \ldots, n$, the index domain. `\n` contains the maximum number of sequence elements, n. `\ifcontinue` is used for controlling loops. The array and the counter `\status` had to be maintained globally, because of the nesting of loops.

1 Typesetting elements

After sorting the typesetting must be done. In general this is dependent upon the application and will demand Hi-TEXnique.[9] For simplicity and in order to concentrate on the sorting aspects I typeset the sequence element after element, via `\prtn`, or `\prtw`.

Example (Typesetting a number sequence)[10]

```
\def\1{314}\def\2{1}\def\3{27}\n3 \prtn
```

yields: **314, 1, 27**.

Example (Typesetting a word sequence)

```
\def\1{ik}\def\2{j\ij}\def\3{h\ij}\n3 \prtw
```

yields: **ik jij hij**.

1.1 TEX encoding

Design choice. The elements are typeset in the default font. The separator is parameterized into `\sep`. Number sequences are typeset in range notation.

Input. The array `\`$\langle k\rangle$, $k = 1, 2, \ldots, n$, and the counter `\n` with value $\langle n\rangle$,[11] and optionally a value $\langle kzero\rangle, \geq 0$, in `\kzero`.

[6] Adaptable to other ligatures and accents.

[7] Ben Lee User, BLU for short, can always page through the provided headings and grasp 'what it is all about' from the included examples.

[8] The file `sort.tex` contains also `\prtind`, to typeset `index.tex`.

[9] Think for example of Knuth's typesetting of the index of the TEXbook, p. 261–263. It is in the chapter on OTR-s (Output Routines) with aura '... the following material will take you all the way to the rank of Grandmaster, i.e., a person who can design output routines.'

[10] In the examples `\def`-s are used to define a one digit as control symbol. `\csname...\endcsname` must be used for two or more digits.

[11] The defaults for the parameter `\sep`—`\sepn`, respectively `\sepw`—are provided in the file `sort.tex`.

Result. The array $\langle kzero+1\rangle : \langle n\rangle$ is typeset. `\kzero` is default 0.

The macros

```
\def\prts{{\k\kzero%print \1,...\n
 \def\sep{\let\sep\sepw}%
 \loop\ifnum\k<\n\advance\k1
    \sep\csname\the\k\endcsname
 \repeat}}\let\prtw\prts
%
\def\prtn{{\k\kzero%Print ranges
 \loop\ifnum\k<\n\advance\k1
  \ea\prc\csname\the\k\endcsname
 \repeat\prtfl}}
%
\def\prc#1{\init{#1}\def\prc##1{%
 \ifnum##1=\lst\else\ifnum##1=\slst
    \lst\slst\advance\slst1 \else
       \prtfl\sepn\init{##}\fi\fi}}
%
\def\prtfl{\the\frst\ifnum\frst<\lst
 \advance\frst1 \ifnum\frst=\lst\sepn
   \else\nobreak--\nobreak\fi\the\lst}
%
\def\init#1{\frst#1\lst#1\slst#1\advance
 \slst1{}}
```

Explanation. Abstraction of the lower index into `\kzero`, default 0, makes it possible to typeset parts of the array. The elements are separated by the separator given in, `\sepn`, respectively `\sepw`. The encoding is TEX specific. Each first time the loop is traversed the invokation of `\sep` redefines itself with the actual separator. On subsequent traversals the provided separator is typeset.

The replacement text of `\prtn` and `\prtw` is a group, and therefore the loop's `\body` cannot redefine the `\body` of an outer loop.

In order to account for number ranges `\prtn` uses `\prc`, a simplified version of `\processc`, borrowed from [25].

2 Storing a sequence

As data structure the following TEX-specific encoding[12] is used.

$$\texttt{\csname}\langle k\rangle\texttt{\endcsname},\quad k=1,2,...,n.$$

Writing to, respectively reading from, the k^{th} element goes via[13]

$$\texttt{\ea\def\csname}\langle k\rangle\texttt{\endcsname}\{\langle k^{th}elem.\rangle\},$$

and

$$\texttt{\csname}\langle k\rangle\texttt{\endcsname}.$$

When a counter `\k`, which takes the values $1,2,\ldots,n$, is used, then TEX requires `\the\k` for the index number $\langle k\rangle$.

To get the hang of it. The reader must be aware of the differences between

- the index number, $\langle k\rangle$
- the counter variable `\k`, with the value $\langle k\rangle$ as index number
- the control sequences $\backslash\langle k\rangle, k=1,2,\ldots,n$, with as replacement texts the items to be sorted.

When we have `\def\3{4} \def\4{5} \def\5{6}` then
`\3` yields **4**,
`\csname\3\endcsname` yields **5**, and
`\csname\csname\3\endcsname\endcsname` yields **6**.

Similarly, when we have
`\k3 \def\3{name} \def\name{action}` then
`\the\k` yields **3**,
`\csname\the\k\endcsname` yields **name**, and
`\csname\csname\the\k\endcsname\endcsname` yields **action**.[14] To exercise shorthand notation the last can be denoted by `\val{\val{\the\k}}`.

Another `\csname...` will execute `\action`, which can be whatever you provided as replacement text.

2.1 From copy

Elements available in the copy of an author are stored via

$$\texttt{\seq}\langle sequence\rangle\texttt{\qes}.$$[15]

Example (Storing numbers from copy)
`\seq1 314 27\qes` stores the elements. For verification `\prtn` yields: **1, 314, 27**.

Example (Storing words from copy)
`\seq ik j{\ij} h\ij\qes` stores the elements. For verification `\prtw` yields: **ik jij hij**.

TEX encoding

Design choice. The sequence is stored in an array via the FIFO TEXnique [23]. The process is independent of the type. Numbers or words (text) can be stored by the same macro.

Input. Data from the user copy preceded by `\seq` and followed by the separator `\qes`. The elements must be separated by a ␣, which is not gobbled by TEX's mouth. (In practice this means that words ending with a control sequence—`\i`, `\j`, or for Dutch `\ij`—must have braces around that control sequence.)

[12] Functionally equivalent to an array. Amy Hendrickson [15] used arrays in TEX although she did not call them as such. Adrew Greene [13], while playing around in TEX's mind, associated already the array concept with `\csname...`.

[13] Actually, I used `\gdef`-s, `\xdef`-s, and `\the\k`.

[14] Confusing, but powerful!

[15] Mnemonics: sequence. This abstracts from all the `\def`-s, casu quo `\csname...\endcsname`-s, as provided in the examples.

Result. The array $\langle k \rangle,\ k = \langle kzero + 1 \rangle, 2, \ldots, n,$ with the sequence elements as values. The counter `\n` will contain the value $\langle n \rangle$. $\langle kzero \rangle$ is a bias, with default value 0.

The macros

```
\def\seq#1\qes{%
          \k\kzero\fifow#1 \wofif{} }
%
%and auxiliaries
\def\fifow#1 {\ifx\wofif#1\n\k\wofif\fi
 \processw{#1}\fifow}
               \def\wofif#1\fifow{\fi}
%
\def\processw#1{\advance\k1
 \ea\gdef\csname\the\k\endcsname{#1}}
```

Explanation. The idea is that the elements from the copy enclosed by `\seq` and `\qes`—and appended in the macro `\seq` by `␣\wofif{}␣`[16]—are processed as arguments of the macro `\fifow`. This macro has a `␣` as endseparator. When `\wofif` is encountered the number of elements is stored in `\n` and the recursion is terminated by the invokation of `\wofif`. The latter macro gobbles all the tokens—in this case `\fi \processw{#1}`—up to and including the next invokation of `\fifow`. Its replacement text inserts a new `\fi`, to correct the disturbed `\if...\fi` balance.

The macro `\processw` maintains the (index) counter and actually stores each element, globally.

2.2 From a file

In applications the words (and other information like page numbers[17] for index preparation) are gathered into a file for later, usually external, processing.

Example (Storing from file)
If the file `index.tex` contains the records

```
word !3 314
word !1 27
tag !1 1
word !1 1
```

then

```
\storefrom{index.tex}
```

stores the elements from the file into the array.

For verification the array is printed by

```
\begin{quote}
\let\sepw\\\prtw\unskip.
\end{quote}
```

with result[18]

word !3 314
word !1 27
tag !1 1
word !1 1

TEX encoding

Specification. Records from a user specified file are to be read into the array. On termination the counter `\n` contains the number of stored elements.

Input. The file with the elements given per line. `\kzero` is default 0.

Result. The array $\langle k \rangle,\ k = \langle kzero \rangle + 1, 2, \ldots, n,$ with the elements as values. `\n` contains the upper bound of the array, $\langle n \rangle$.

The macro

```
\def\storefrom#1{%#1 is file name
 \openin\rec#1 \k\kzero \continuetrue
 \loop\ifeof\rec\continuefalse\fi
 \ifcontinue\advance\k1 \read\rec to\xyz
  \ea\global\ea\let\csname\the\k\endcsname\xyz
 \repeat\advance\k-1\n\k\closein\rec}
```

Explanation. The `\newread\rec` has been specified in the file `sort.tex`. TEX appends a `\par` to the opened file, therefore I had to decrement the counter `\k` by 1 at the end. After `\rec#1` a `␣` is mandatory; an empty group is not recognized as terminator. Because of the lack of an `\ifnoteof` and of the way `\loop` has been encoded—TEXbook, p. 219, an `\else` cannot be used in the body of the loop as part of the termination—I used the `\newif\ifcontinue` for controlling the loop. The bias $\langle kzero \rangle$ is handy for merging index files.

2.3 From a generator

Although the automatic generation of data is only used in the tests, it seemed worthwhile for me to include these macros too, as an example of how data can be created and stored.

Numbers

A random number generator—the macro `\rnd`—has been encoded in TEX by Reid [30]. I added `\storerandomn` to store the specified number of random numbers in the array.

Example (Storing random generated numbers)

```
\rndnum5 \storerandomn5\prtn
```

yields:[19] **1, 88, 62, 27, 1.**

[16] The empty group is needed because spaces after control sequences are gobbled. Beware!

[17] Known by the OTR—Output Routine—only. For writing the index reminders to the file `index.tex` see the TEXbook, p. 424, the macro `\writeit` and auxiliaries. A simplified encoding will be provided in Manmac BLUes, see elsewhere in this MAPS.

[18] Note that I had to add an `\unskip`. `\\` is LATEX's newline.

[19] More clearly, I could have provided `\rndnum=5␣` and `\storerandomn{5}`, to emphasize the different syntactical roles of the number 5.

The macros. The encoding of my macro is straightforward, once I decided to use Reid's random generator macro, \rnd [30].

```
\def\storerandomn#1{%#1 number
                    %of r-numbers
 \n#1\k0{\loop\ifnum\k<\n\advance\k1 %
                               \rnd\ea
  \xdef\csname\the\k\endcsname{%
                   \the\rndval}%
 \repeat}}
%
\def\rnd{\global\multiply\rndnum371
 \global\advance\rndnum1
 \ifnum\rndnum>99999
  \rndtmp\rndnum \divide\rndtmp100000
  \multiply\rndtmp100000
  \global\advance\rndnum-\rndtmp
 \fi\global\rndval\rndnum
 \global\divide\rndval1000 }
```

Words

Reid [30] introduced his macros for generating random paragraphs. I added \storerandomw to store the specified number of random words in the array.

Example (Storing random generated words)

```
\rndnum5 \storerandomw5\prtw
```

yields: **ajqjjhfn fyi uednas ahw zr.**

The macros

```
\def\storerandomw#1{%#1 number of words
 \n#1\nw\n{\loop\ifnum0<\nw
  {\ag\defarr\ag{\randomword}}%
                          \advance\nw-1
 \repeat}}%end s-r-w.
%
\def\defarr{\ea\gdef%
               \csname\the\nw\endcsname}
%
\def\randomword{\rnd\nc\rndval
 \divide\nc15\advance\nc2
 \loop\ifnum0<\nc\randomchar%
                           \advance\nc-1
 \repeat}%end r-word
%
%Random character is modified
\def\randomchar{\rnd
 \multiply\rndval29\divide\rndval100
 \ifnum\rndval=26\rndval0 \fi
 \ifnum\rndval>26\rndval4 \fi
%Mod cgl: I \ag-ed the letter
 \ea\ag\ifcase\rndval
  a\or b\or c\or d\or e\or f\or g\or h\or
  i\or j\or k\or l\or m\or n\or o\or p\or
  q\or r\or s\or t\or u\or v\or w\or x\or
  y\or z\fi}
```

Explanation. Although the same approach as for storing random generated numbers has been followed, I had to modify the code due to the need for intermediate storing of each random generated letter. A random word consists essentially of random numbers, mapped onto letters. The numbers are generated in an inner loop, via Reid's macro \randomchar. Because of the nesting of loops I had to group the inner loop. Realizing this, prompted a TEX specific way for storing the letters generated in the inner loop. The letters are placed after the enclosing group via \aftergroup. When the group is ended the word is stored as replacement text of $\backslash\langle nw\rangle$. (The tokens for the definition are \ag-ed before the inner loop; the closing brace is already after the innerloop.)

3 Sorting of numbers

Example

\seq314 1 27\qes\sortn yields: **1, 27, 314**.

3.1 Design choices

The backbone of my 'sorting in an array' is the data structure

$$\backslash\text{csname}\langle k\rangle\backslash\text{endcsname}\{\langle k^{th}elm.\rangle\},\quad k=1,2,\ldots,n,$$

with k the role of array index and n the number of items to be sorted.

The encoding is parameterized by \cmp, the comparison macro, which differs for numbers, strings, and in general when more sorting keys have to be dealt with.[20] The result of the comparison is stored globally in the counter \status.

3.2 TEX encoding

Input. The elements are assumed to be stored in the array $\backslash\langle k\rangle$, $k=1,2,\ldots n$. The counter \n must contain the value $\langle n\rangle$.

Result. The sorted array \1, \2, ... $\backslash\langle n\rangle$, with $\backslash\text{val}1 \le \backslash\text{val}2 \le \ldots \le \backslash\text{val}\langle n\rangle$.

The macros

```
\def\sortn{\let\cmp\cmpn\sort\prtn}
%
\def\cmpn#1#2{%#1, #2 must expand into numbers
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}.
 \ifnum#1=#2\global\status0 \else
  \ifnum#1>#2\global\status1 \else
             \global\status2 \fi\fi}
%
\def\sort{\heapsort}.
```

Explanation. The above shows the structure of each of the Ben Lee User sorting macros.

Sorting: \sortn. A (pointer) \def\sortn{...} is introduced which has as replacement text the setting of the parameter \cmp, and the invokations of the actual sorting macro and the macro for typsetting the sorted sequence.

[20] For an example see the sorting of Knuth's index reminders in section 5.

Comparison operation: `\cmpn`. The result of the comparison is stored globally in the counter `\status`. The values $0, 1, 2$ denote $=, >, <$, respectively.

Exchange operation: `\xch`. The values can be exchanged via[21]

```
\def\xch#1#2{%#1, #2 counter variables
 \edef\aux{\csname\the#1\endcsname}\ea
 \xdef\csname\the#1\endcsname{\csname
   \the#2\endcsname}\ea
 \xdef\csname\the#2\endcsname{\aux}}.
```

3.3 Some testing

Apart from the examples as given above, `\sortn` has been tested on sequences of random numbers. Some idea of the efficiency was obtained and no reasonable restrictions with respect to the number of items to be sorted, other than the installation limitations, were encountered. For this purpose use has been made of Reid's random number generator in TEX, `\rnd` [30].

Timings. On my 8086 MS-DOS PC `\sortn` (without time needed to create the array, but with the time needed to write the sorted array to the dvi-file) had the (near-linear) performance

No	≈ Time
15	13 seconds
50	1 minute
200	5 minutes.

The University's VAX8650[22] needed ≈ 1.75 minutes for sorting 500 numbers.[23] The measurements were done with `\heapsort` as sorting macro.

3.4 Variation

For short sequences algorithms of complexity $O(n^2)$ are generally used.[24]

```
%O(N*N) sorting.
\def\sort{\bubblesort}
%
\def\bubblesort{%Data in \1, \2,...\<n>.
{\loop\ifnum1<\n{\k\n
  \loop\ifnum1<\k\advance\k-1 \cmp\k\n
   \ifnum1=\status\xch\k\n\fi
  \repeat}\advance\n-1
 \repeat}}%end \bubblesort
```

4 Lexicographic sorting

Given the blue collar workers `\heapsort`, respectively `\quicksort`, we have to encode the comparison macro in compliance with the parameter macro `\cmp`. But, ... lexicographic sorting is more complex than number sorting. We lack a general comparison operator for strings,[25] and we have to account for ligatures and diacritical marks.

In creating a comparison macro for words, flexibility must be built in with respect to the ordering of the alphabet, and the handling of ligatures and diacritical marks.

Example (Sorting ASCII words)

```
\seq a b aa ab bc bb aaa\qes\sortw
```
yields: **a aa aaa ab b bb bc**.

Example (Sorting words with ij-ligature)

```
\seq{\ij}st{\ij}d {\ij} {\ij}s in tik
 t\ij\qes\sortw
```
yields: **in tik tij ij ijs ijstijd**.

Example (Sorting accented words)

```
\seq b\'e b\‘e \'a\'a ge\"urm geur aa a
ge{\ij}kt be ge\"\i nd gar\c con\qes
\sortw
```
yields: **a aa áá be bé bè garçon geïnd geur geürm geijkt**.

Reculer pour mieux sauter. Because of the complexity and the many details involved I recede with simplified cases as stepping stones. I'll first guide you through the encoding of the comparison macro for

- one-(ASCII)letter-words, and
- ASCII strings, of undetermined length,

after which we will come back to the main track of the encoding of the general comparison macro.

One-(ASCII)letter-words. The issue is to encode the comparison macro, in compliance with the parameter macro `\cmp`. Let us call this macro `\cmpolw`.[26] Its task is to compare one-letter words and store the result of each comparison globally in the counter `\status`. As arguments we have `\def`-s with one letter as replacement text.

```
\def\cmpolw#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}.
 \ea\chardef\ea\cone\ea‘#1{}%
 \ea\chardef\ea\ctwo\ea‘#2{}%
 \global\status0 \lge\cone\ctwo}
%
\def\lge#1#2{%#1, #2 are letter values
```

[21] For a better and more general macro, see section 4 about lexicographic sorting. Here the definitions are completely expanded, which is not necessary and therefore inefficient.

[22] Just to give the reader an idea because VMS is a time sharing system.

[23] As expected with 0–99 as printed result. Neat!

[24] A nice example of encoding nested loops. Should be part of courseware about macro writing in TEX.

[25] It is not part of the language, nor provided in plain. Victor Eijkhout [10] supplied one. The (limited) predecessor of my comparison macro has appeared in [23]. Those macros don't abstract from the ASCII ordering or allow for accented words and ligatures.

[26] Mnemonics: compare one letter words.

```
%Result: \status= 0, 1, 2 if #1 =, >, < #2. \let\cmp\cmpaw\sort\prtw.
 \ifnum#1>#2\global\status1 \else
   \ifnum#1<#2\global\status2 \fi\fi}
%
\seq z y A B a b d e m n o p z z u v c g
q h j I i l k n t u r s f Y\qes
\let\cmp=\cmpolw\sort\prtw
```

The above yields: **A B I Y a b c d e f g h i j k l m n n o p q r s t u u v y z z z**.

Explanation `\cmpolw`**..** In order to circumvent the abundant use of `\expandafter`-s, I needed a two-level approach: at the first level the letters are 'dereferenced,' and the numerical value of each replacement text is provided as argument to the second level macro, `\lge`.[27]

ASCII words. The next level of complexity is to allow for strings, of undetermined length and composed of ASCII letters. Again the issue is to encode the comparison macro, in compliance with `\cmp`. Let us call the macro `\cmpaw`[28]. Its task is to compare ASCII words and store the result of each comparison globally in the counter `\status`.

The problem is how to compare strings letter by letter. Empty strings are equal. This provides a natural initialization for the `\status` counter. As arguments we have `\def`-s with words of undetermined length as replacement text.

```
\def\cmpaw#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}.
 {\let\nxt\nxtaw\cmpc#1#2}}
%
\def\cmpc#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}.
\global\status0 \continuetrue
{\loop\ifx#1\empty\continuefalse\fi
      \ifx#2\empty\continuefalse\fi
 \ifcontinue\nxt#1\nxtt \nxt#2\nxtu
     \lge\nxtt\nxtu
     \ifnum0<\status\continuefalse\fi
 \repeat}\ifnum0=\status
 \ifx#1\empty\ifx#2\empty\else
                 \global\status2 \fi
 \else\ifx#2\empty\global\status1 \fi
 \fi\fi}
%
\def\nxtaw#1#2{\def\pop##1##2\pop{\gdef
 #1{##2}\chardef#2'##1}\ea\pop#1\pop}
%
\seq a b aa ab bc bb aaa\qes
```

The above yields: **a aa aaa ab b bb bc**.

Explanation

Comparison: `\cmpaw`**..** The macro is parameterized over the macro `\nxt`. The main part of `\cmpaw` has been encoded as `\cmpc`. (That part is also used in the general case.)

We have to compare the words letter by letter. The letter comparison is done by the already available macro `\lge`. The `\lge` invokation occurs within a loop, which terminates when either of the strings has become empty. I added to stop when the words considered so far are unequal. At the end the status counter is corrected if the words considered are equal and one of the #-s is not empty: into 1, if #1 is not empty, and into 2, if #2 is not empty.

Head and tail: `\nxt`**..** The parameter macro `\nxt` has the function to yield from the replacement text of its first argument the ASCII value of the first letter and deliver this value as replacement text of the second argument.[29] The actual macro `\nxtaw` pops up the first letter and delivers its ASCII value—a `\chardef`—as replacement text of the second argument. Note that the first parameter is globally redefined for the emptiness-test after the loop.

4.1 Design choices

Sorting of words with ligatures and accents is done via the ordering defined in a so-called ordering table.[30] This entails that the comparison of letters has to be generalized such that accents are recognized too. For the (accented)letter-to-number conversion the ` is replaced by a table look-up.

Comparison operation. A special situation arises with diacritical marks. Within the context of sorting the commands for diacritical marks have been redefined with the function to provide for the control symbol together with the accompanying letter an appropriate value from the ordering table.

Note that when the ASCII ordering is sufficient, no ordering table is needed. For that case `\cmp` can be `\let`-equal to `\cmpaw`.

Ordering table. In Dutch the ij is peculiar. It is mostly used as a ligature[31] and in that role its lexicographic position is between `x` and `z`.[32] This character is not accounted for in the ASCII table, therefore we

[27] Mnemonics: letter greater or equal. A nice application of the use of `\ea`, `\chardef`, and the conversion of a character into a number: `'`. Note that the values of the upper case and lower case letters differ (by 32) in ASCII.

[28] Mnemonics: compare ASCII words.

[29] Splitting up into 'head and tail,' is treated in the TEXbook, Appendix D.2, p. 378, the macro `\lop`. There use has been made of token variables instead of `\def`-s.

[30] In the ordering table numbers are associated to letters, ligatures and accented letters.

[31] Also as two characters. For example in bi-jection (hyphen for emphasis) and the like.

[32] I was quite surprised to find out that my Dutch dictionary does *not* sort on the ij-ligature?!?

need an ordering table. In some other languages similar situations exist, so the idea of abstraction from the ASCII ordering is useful,[33] if not for the handling of diacritical marks. For the input I adopted the convention to supply `\ij`. The ordering table is implemented via a list of `\chardef`-s.[34] Numbers are not assigned consecutively in the ordering table, leaving room for accented letters.

I have provided the same values for upper and lower case letters. The successor values are reserved for the accents: acute, grave, umlaut, and hat. I also accounted for the cedille.

4.2 TEX Encoding

Purpose. To sort words with (Dutch) accents and ij-ligature.

Input. The elements are assumed to be stored in the array $\backslash\langle k\rangle$, $k = 1, 2, \ldots n$. The counter `\n` must contain the value $\langle n\rangle$.

The default settings are done in the file `sort.tex`. The macro `\accdef` contains the modified accent definitions, and the macro `\accstr` the string of accent control sequences.

Result. The sorted array `\1`, `\2`, $\ldots$ $\backslash\langle n\rangle$, with `\val1` $\leq$ `\val2` $\leq \ldots \leq$ `\val`$\langle n\rangle$.

The macros

```
%Modifications/addenda to number sorting
%Sorting and typesetting.
\def\sortw{{\accdef\let\cmp\cmpw\sort}%
                                    \prtw}
%
%Compare words.
\def\cmpw#1#2{%#1, #2 are def-s.
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}.
 \let\nxt\nxtw\cmpc#1#2}
%
%Yield value of next (accented) letter.
\def\nxtw#1#2{\def\pop##1##2\pop{%
 \gdef#1{##2}\def\head{##1}}%tail and head
 \ea\pop#1\pop
 \ea\loc\head\accstr%\head in accentcs?
 \iffound\let\acs\head
  \ea\pop#1\pop%next tail and head
  \ea\let\ea#2\csname ot\acs\head\endcsname
 \else\ea\let\ea#2\csname ot\head\endcsname
 \fi}
%
\def\accstr{\'\`\"\^\c}
%
\def\accdef{%
 \def\'##1{##1g}\def\`##1{##1a}
                                %acute grave
 \def\"##1{##1t}\def\c##1{##1c}
                                %trema cedille
 \def\^##1{##1h}%hat
 \def\i{i}\def\j{j}}%dotless i, j

\def\loc#1#2{\def\locate##1#1##2\end
 {\ifx\empty##2\empty\foundfalse
 \else\foundtrue\fi}\ea\locate#2.#1\end}
%
%Ordering table
\chardef\ota32 \chardef\otA32
 \chardef\otaa33 \chardef\otag33
 \chardef\otat34 \chardef\otah35
%et cetera, see Appendix C
```

Explanation

Sorting: `\sortw`. A (pointer) `\def\sortw{...}` is introduced, which has as replacement text the insertion of the accent definitions via the invokation of `\accdef`, the setting of the parameter `\cmp`, and the invokations of the actual sorting macro and the macro for typesetting. A group is used in order to keep the temporary redefinitions of the accents local. `\accdef` yields the modified definitions for the accents and special letters like `\i`, and `\j`. The purpose of these definitions is to get the right value from the ordering table.

Comparison operation: `\cmpw`. The parameter macro `\nxt` is `\let`-equal to `\nxtw`. The comparison is done by the common `\cmpc`,[35] which stores globally the result of the comparison in the counter `\status`.

Head and tail: `\nxtw`. This macro peels a token[36] from the first argument, selects the associated value form the ordering table and delivers the latter value in the second argument, as a `\chardef`. The complication is that when we have an accent we have to consider the next token too, and select the associated numerical value for the combination.[37]

The remainder of the word, the tail, is delivered globally in the first argument, for the afterloop emptiness-test. The local macro `\pop` yields the head and the tail of a word. `\loc` determines whether the token in `\head` is an accent control symbol.[38]

Exchange operation: `\xch`. No expansion of the accents must take place, therefore the already stored data are copied via the `\let`-equal TEXnique.

```
\def\xch#1#2{%#1, #2 counter variables
```

[33] As communicated by Wlodek Bzyl, with respect to Czech.

[34] Remember that a `\chardef` name can be used as a number.

[35] For an explanation see the subsection about ASCII words.

[36] Or debraced group.

[37] A neat use of `\ea`, `\let`, and `\csname...`, with as result a `\chardef`!

[38] This is a generalization of the search for $\langle char\rangle \in \langle string\rangle$ [23]. On second thoughts, I consider this a neat generalization. The temporary redefinitions are parameterized into `\def\accdef...` .

```
\ea\let\ea\auxone\csname\the#1\endcsname
\ea\let\ea\auxtwo\csname\the#2\endcsname
\ea\global\ea\let\csname\the#2\endcsname
\auxone
\ea\global\ea\let\csname\the#1\endcsname
\auxtwo}.
```

To verify your understanding, what is the result[39] of

```
\m3\n4\def\3{first}\def\4{second}
\xch\m\n
\the\m, \the\n; \3, \4.
```

4.3 Some testing

Apart from the examples as given above, lexicographic sorting has been tested on sequences of random words. For this purpose use has been made of Reid's [30] work for generating random paragraphs in TEX.

Timings. On my 8086 MS-DOS PC the (word) sorting, without the time needed to create the array but with the time needed to write to the dvi-file, had the performance

No	≈ Time
15	30 seconds
50	3 minutes.

The University's VAX8650[40] needed ≈ 5 minutes to sort 500 random words. The measurements were done with `\heapsort` as sorting macro, with each word of random length.

5 Applications

5.1 Sorting address labels

Amy Hendrickson [15] used sorting of address labels to illustrate various macro writing TEXniques. However, she used external sorting routines. Here I will do the sorting within TEX, and enrich her approach further by separating the mark-up phase from the data base query and the report generating phases. Because this paper concentrates on sorting aspects, let us assume that each address is supplied as a definition, with the definitions of the name and address components as replacement text. Furthermore, it is handy to create a list of all the addresses: the names of the address definitions separated by `\as`, the address separator.[41] For the imaginative toy adresses of the three composers: Schönberg, Webern, Strawinsky, the structures look like as follows.

```
\def\schonberga{\def\initial{A}
 \def\sname{Arnold}\def\cname{Sch\"onberg}
 \def\street{Kaisersallee}\def\no{10}
 \def\county{}\def\pc{9716HM}
 \def\phone{050-773984}\def\email{as@tuw.au}
 \def\city{Vienna}\def\country{AU}}
%
\def\strawinskyi{\def\initial{I}
 \def\sname{Igor}\def\cname{Strawinsky}
 \def\street{Longwood Ave}\def\no{57}
 \def\county{MA}\def\pc{02146}
 \def\phone{617-31427}
 \def\email{igor@ai.mit.edu}
 \def\city{Boston}\def\country{USA}}
%
\def\weberna{\def\initial{A}
 \def\sname{Anton}\def\cname{Webern}
 \def\street{Amstel}\def\no{143}
 \def\county{Noord-Holland}\def\pc{9893PB}
 \def\phone{020-225143}\def\email{aw@uva.nl}
 \def\city{Amsterdam}\def\country{NL}}
%
%and the list
\def\addresslist{\as\strawinskyi
 \as\weberna\as\schonberga}
```

For the typesetting I made use of the following simple address label format[42]

```
\def\tsa{%The current address info is set
 \par\initials \cname \par
 \no\ \street\ \city\par
 \pc\ \county\ \country\par}
%
\def\initials{\ea\fifo\initial\ofif}
\def\fifo#1{\ifx\ofif#1\ofif\fi#1. \fifo}
\def\ofif#1\fifo{\fi}
```

Example (Database query: selection of addresses per country)
Suppose we want to select (and just `\tsa` them for simplicity[43]) the inhabitants from Holland from our list. This goes as follows.

```
\def\search{NL}
\def\as#1{#1\ifx\country\search\tsa\fi}
\addresslist
```

The above yields the result
A. Webern
143 Amstel Amsterdam
9893PB Noord-Holland NL

[39] Answer: 3, 4; second, first.

[40] Just to get the flavor of it because VMS is a time sharing system.

[41] By this set-up we can do a lot more than just sorting address labels. What about mailmerge? What about 'TEX as a database report generator?' Jurriens [18] coined the term, although most of the work there was done via UNIX scripts.

[42] The encoding of printing special address labels has been worked out by for example Damrau & Wester [7]. It is left as an exercise to the reader to modify `\tsa` such that address labels are typeset in an m-by-n grid, each label of size h-by-w with parameters m, n (counters), and h, w (dimensions).

In this example `\initials` is not used. It has been added to allow for multiple initials of which all letters must end with a period.

[43] We could also create a new address list for that country and apply another query, or just sort.

Example (Sorting address labels)
Amy's example can be done completely within TEX, as follows.

```
%Prepare sorting
\def\as#1{\advance\k1 \ea\xdef\csname
 \the\k\endcsname{\ea\gobble\string#1}}
%
\def\gobble#1{}
%
\k0{}\addresslist%Create array to be sorted
\n\k\def\prtw{}%Suppress default \prtw
\sortw%Sort the list
%Typeset addresses, alphabetically ordered
\k0
\loop\ifnum\k<\n\advance\k1
 \csname\csname\the\k\endcsname\endcsname
 \vskip1ex\tsa
\repeat
```

The above yields the results

A. Schönberg
10 Kaisersallee Vienna
9716HM AU

I. Strawinsky
57 Longwood Ave Boston
02146 MA USA

A. Webern
143 Amstel Amsterdam
9893PB Noord-Holland NL

Remarks. The automatic mark-up of address data supplied in a TEX independent way, is not the subject of this paper. The given set-up allows to add, in any order, the address information to the database, under the restriction that definitions with the same names must be used for the address components.[44] The list must be modified too.

As can be seen from the above, and also in Amy's free format, it is not easy to keep the file ordered while extending the database. Therefore sorting is needed, such that the database can be extended in an arbitrary way. Database TEXniques have it that modifications to the data are independent from the report generating, thanks to the sorting tools.

5.2 Sorting Knuth's index reminders

An index reminder, as introduced by Knuth, consists of index material to be further processed for typesetting an index. In the TEXbook, p. 424, Knuth gives the syntax of an index reminder

$$\langle word\rangle\sqcup!\langle digit\rangle\sqcup\langle page\ number\rangle.$$

The reminders, one per line, are written to a file because only the OTR knows the page numbers. Knuth considered this file, `index.tex`,

> '. . . a good first approximation to an index.'

He also mentions the work of Winograd and Paxton [36][45] for automatic preparation of an index. Here we will provide a second approximation to an index: the index reminders are sorted and compressed. The sorting is done on the three keys

primary key: $\langle word\rangle$
secundary key: $\langle digit\rangle$, and
tertiary key: $\langle page\ number\rangle$.

The compressing comes down to reducing the index reminders with the same $\langle word\rangle$ $\langle digit\rangle$ part to one, with instead of one page number all the relevant page numbers in non-decreasing order.

We assume that the index reminders are already stored in the array.[46] Similarly, I didn't bother about writing the sorted and reduced array to a file. It is up to the index preparator what to do with the array and how to typeset it. Furthermore, it is not complete, because of subentries, subsubentries, or 'see. . . ,' and 'see also. . . ,' which are not considered here.[47]

Example (Sorting on primary, secundary and tertiary keys)

```
\def\1{z !3 1}\def\2{a !1 2}\def\3{a !1 3}
\def\4{a !1 1}\def\5{ab !1 1}\def\6{b !0 1}
\def\7{aa !1 1}\def\8{a !2 2}\def\9{aa !1 2}
\n9\k0\kk0
\let\cmp\cmpir\sort\let\sepw\\\null
\hfil\vtop{\hsize2cm\noindent
 after sorting\\[.5ex]\prtw}
\hfil\vtop{\hsize2.5cm\noindent
 after reduction\\[.5ex]\redrng\prtw}
\hfil\vtop{\hsize2cm\noindent
 typeset in\\index:\\[.5ex]\prtind.}\hfil
```

The above yields[48]

after sorting:	after reduction:	typeset in index:
a !1 1	a !1 1–3	a 1–3
a !1 2	a !2 2	\a 2
a !1 3	aa !1 1, 2	aa 1, 2
a !2 2	ab !1 1	ab 1
aa !1 1	b !0 1	b 1
aa !1 2	z !3 1	⟨z⟩ 1.
ab !1 1		
b !0 1		
z !3 1		

[44] Of course one can change the chosen names.

[45] Later Lamport provided makeindex and Salomon a plain version of it, to name but two persons who contributed to the development. The Winograd Paxton Lisp program is also available in Pascal.

[46] The process for storing the contents of `index.tex` in the array `\1`, `\2`,. . . ,$\backslash\langle n\rangle$, has been described in Storing from a file, section 2, and will not be repeated here.

[47] An approach to handle sub(sub)entries is to allow for composite primary keys, for example separated by `\se`, respectively `\sse`. In `\decom, and \typind` we have to account for the various possibilities. I will come back to the issue of typesetting Indexes within TEX, another time.

[48] The unsorted input can be read from the verbatim listing.

Design

Given the sorting macros we just have to encode the special comparison macro in compliance with `\cmpw`: compare two 'values' specified by `\def`-s. Let us call this macro `\cmpir`.[49] Each value is composed of

- a word (action: word comparison),
- a digit (action: number comparison), and
- a page number (action: (page) number comparison).

The macros read as follows.

```
\def\cmpir#1#2{%#1, #2 defs
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}
 \ea\ea\ea\decom\ea#1\ea;#2.}
%
\def\decom#1 !#2 #3;#4 !#5 #6.{%
 \def\one{#1}\def\four{#4}\cmpaw\one\four
 \ifnum0=\status%Compare second key
   \ifnum#2<#5\global\status2 \else
     \ifnum#2>#5\global\status1 \else
       %Compare third key
       \ifnum#3<#6\global\status2
       \else\ifnum#3>#6\global\status1 \fi
       \fi
     \fi
   \fi
 \fi}
```

Explanation. I needed a two-level approach. The values are decomposed into their components by providing them as arguments to `\decom`.[50] The macro picks up the components

- the primary keys, the $\langle word \rangle$,
- the secundary keys, the $\langle digit \rangle$, and
- the tertiary keys, the $\langle page\ number \rangle$.

It compares the two primary keys, and if necessary successively the two secondary and the two tertiary keys. The word comparison is done via the already available macro `\cmpaw`.

To let this work with `\sort`, we have to `\let`-equal the `\cmp` parameter to `\cmpir`.

Reducing duplicate word-digit entries

The idea is that the same index entries, except for their page numbers, are compressed into one, thereby reducing the number of elements in the array. Instead of one page number all the relevant page numbers are supplied in non-descending order in the remaining reminder, in range notation. The macro is called `\redrng`[51] and is given below

```
\def\redrng{%Reduction of \1,...,\n, with
%page numbers in range representation
 {\k1\kk0
 \ea\let\ea\record\csname\the\k\endcsname
 \ea\splitwn\record.\let\refer\word
 \let\nrs\empty\prcrng\num
 \loop\ifnum\k<\n\advance\k1
  \ea\let\ea\record\csname\the\k\endcsname
  \ea\splitwn\record.%
  \ifx\refer\word%extend \nrs with number
    \prcrng\num
  \else%write record to \kk
   \advance\kk1 \strnrs \ea\xdef
   \csname\the\kk\endcsname{\refer{} \nrs}
   \let\nrs\empty\init\num\prcrng\num
    \let\refer\word
  \fi
 \repeat\ifnum1<\n\advance\kk1 \strnrs\ea
  \xdef\csname\the\kk\endcsname{\word{}
   \nrs}\global\n\kk\fi}}
%auxiliaries
\def\splitwn#1 !#2 #3.{\def\word{#1 !#2}%
 \def\num{#3}}
%
\def\prcrng#1{\init{#1}\def\prcrng##1{%
 \ifnum##1=\lst\else\ifnum##1=\slst
  \lst\slst\advance\slst1 \else
  \strnrs\init{##1}\fi\fi}}
%
\def\strnrs{\dif\lst\advance\dif-\frst
 \edef\nrs{\ifx\nrs\empty\else\nrs\sepn\fi
  \the\frst\ifnum0<\dif
   \ifnum1=\dif\sepn\the\lst
   \else\nobreak--\nobreak\the\lst
   \fi
  \fi}}
```

Explanation. The encoding is complicated because while looping over the index reminders either the reminder in total or just the page number has to handled. The handling of the page numbers is done with modified versions of `\prc`, `\prtfl`, called respectively `\prcrng` and `\strnrs`.[52] I encoded to keep track of the numbers in the macro `\nrs`, in the case of duplicate word-$digit$-entries. Another approach is while typesetting the array element to process the page numbers via `\prc` [25].

Typesetting index entries

Knuth has adopted the following conventions for coding index entries.

Mark up	Typeset in copy*	In `index.tex`
`^{...}`	...	`... !0` $\langle page\ no \rangle$
`^^{...}`	'silent'	`... !0` $\langle page\ no \rangle$
`^|...|`	|...|	`... !1` $\langle page\ no \rangle$
`^|\...|`	|\...|	`... !2` $\langle page\ no \rangle$
`^|<...>|`	$\langle ... \rangle$	`... !3` $\langle page\ no \rangle$

* `|...|` denotes manmac's, TUGboat's,... verbatim.

[49] Mnemonics: compare index reminders

[50] Mnemonics: decompose. In each comparison the def-s are 'dereferenced,' that is their replacement texts are passed over. This is a standard TEXnique: a triad of `\ea`-s, and the hop-over-s to the second argument.

[51] Mnemonics: reduce (in range notation). The macro `\red`, which does not yield the page numbers in range notation is supplied in the file `sort.tex` too.

[52] Mnemonics: processc with ranges, respectively store numbers.

The typesetting as such can be done via the following macro.

```
\def\typind#1{%#1 a def
 \ea\splittot#1.%
 \ifcase\digit\word\or
        {\tt\word}\or
  {\tt\char92\word}\or
  $\langle\hbox{\word}\rangle$\fi{}
 \pagenrs}
%
\def\splittot#1 !#2 #3.{\def\word{#1}%
 \chardef\digit#2{}\def\pagenrs{#3}}
%
\def\prtind{{\def\\{\hfil\break}\k\kzero
 \def\sep{\let\sep\sepw}%
 \loop\ifnum\k<\n\advance\k1 \sep
  \ea\typind\csname\the\k\endcsname
 \repeat}}
```

The typesetting of the index à la TEXbook Appendix I has been dealt with in the Grandmaster chapter of the TEXbook, p. 261–263.

5.3 More than one index

Erik Frambach posed the following question on the tex-nl@hearn discussion list

> How to prepare automatically two index files: one for commands and one for the rest?

A solution to this problem is to create the information in two files, one for the control sequences and the other for the rest. This works independently of the used tool. Another solution is splitting the `index.tex` file, depending upon the $\langle digit \rangle$ code.[53] Knuth associated control sequences with code 2, when writing the index entry to `index.tex`, TEXbook p. 423.

Example (Separate sorting of control sequences)

```
\def\1{wd !2 7}\def\2{wrd !1 1}
\def\3{wd !2 2}\def\4{a !1 1}
\def\5{wd !2 5}\def\6{wd !2 3}
\def\7{z !3 7}\def\8{wrd !1 5}
\def\9{wd !2 1} \n9
\let\sepw\\\null
\hfil\vtop{\hsize=2cm\noindent
 data:\\[.5ex]\prtw}
\hfil\vtop{\hsize=2.2cm\sortcs\noindent
 after splitting:\\[.5ex] {\n\pk\prtw}
  \\[.5ex]\kzero\pk\prtw}
\hfil\vtop{\hsize2.5cm\let\cmp\cmpir
 {\low1\up\pk\quicksort}
 {\low\pkone\up\n\quicksort}\noindent
 after sorting\\both parts,\\
 compressing,\\and typesetting:\\[.5ex]
 \redrng\n3 \prtind\\[.5ex]\typind\4.}
```

yields[54]

data:	after splitting:	after sorting both parts, compressing, and typesetting:
wd !2 7	wrd !1 5	a 1
wrd !1 1	wrd !1 1	wrd 1, 5
wd !2 2	z !3 7	⟨z⟩ 7
a !1 1	a !1 1	\wd 1–3, 5, 7.
wd !2 5	wd !2 5	
wd !2 3	wd !2 3	
z !3 7	wd !2 2	
wrd !1 5	wd !2 7	
wd !2 1	wd !2 1	

Encoding

```
\def\getdig#1 !#2 #3.{\def\dig{#2}}
%
\def\sortcs{\global\k0\global\pk\n
\global\pkone\pk\global\advance\pkone1
%Invariant: 1:k non-cs-s,
%             and pk+1:n cs-s
\loop\global\advance\k1
\ifnum\k<\pkone
 \ea\ea\ea\getdig\csname\the\k\endcsname.%
 \if2\dig{\continuetrue%        <--
cs<=>2!
  \loop
   \ifnum\k=\pk\global\pkone\pk
    \global\advance\pk-1 \continuefalse
   \else\ea\ea\ea\getdig\csname\the\pk
    \endcsname.%
    \if2\dig\global\pkone\pk
     \global\advance\pk-1
     \ifnum\k=\pk\continuefalse\fi
    \else\xch\k\pk\global\pkone\pk
                  \global\advance\pk-1
     \continuefalse
    \fi
   \fi
  \ifcontinue
  \repeat}%
 \fi
\repeat}%Result\1:\pk non-cs, \pkone:\n cs
```

Explanation. Suppose that the file `index.tex` is stored in the array. Loop through the array and compare the $\langle digit \rangle$ with 2. In case of a control sequence swap this index entry with an appropriate entry at the end.

The invariant of the loop is: $\backslash 1 : \backslash\langle k \rangle$[55] contains no control sequences, and $\backslash\langle pk+1 \rangle : \backslash\langle n \rangle$ contains control sequences.

As result the array is partitioned with the control sequences at the end of the array, that is the replacement texts of $\backslash\langle pk+1 \rangle : \backslash\langle n \rangle$.

[53] Conversely, merging two separate index files is easy, and can be done via `\storefrom{`$\langle 1^{st}$-$file \rangle$`} \kzero\n \storefrom{`$\langle 2^{nd}$-$file \rangle$`}`.

[54] The sorting of the control sequences can be done via a slightly more efficient `\cmpir`, because of the same $\langle digit \rangle$.

[55] Not pk, but k!

6 Epilogue

A glossary or an index is usually processed outside of TEX, that is via other tools. 'How to encode in TEX,' was explored via the classic example of sorting. No robustness was strived after. The encodings have been kept as simple and flexible as possible.[56] As a consequence no attention has been paid to safeguarding goodies like the prevention of name confusions with those already in use by an author.

Silent redefinitions do occur when not alert. Beware!

Looking back. Much of the work has been done in the spirit of

> Abstraction is our only mental tool
> to master complexity E.W. Dijkstra
>
> A professional starts
> where an amateur ends G.E. Forsythe

7 TEXniques used

The printing of a sequence parameterized by the separator.
FIFO and the active list separator to store a sequence in an array.
Parameter separators to select parts of an argument.
Peeling off characters one by one from a string.
Expanding the parameters before the invokation of the macro (Use of triads of `\ea`-s).
Using the ASCII values of characters for comparison.
Transforming numbers into characters.
Generating random elements for testing.
`\ag` to store random generated letters as words.
Setting up an address database.
Selecting from a database via queries implemented via the active list separator.
Maintaining a heap structure.
Initialization of loops and recursion: on first traversal some actions are different from the rest.
Ending recursion via gobbling up the tokens including the invokation for the next level.
Parameterizing sorting with respect to the comparison operation.
`\chardef`-s to parameterize the ordering table of the alphabet.
Sorting (accented) words.
Sorting on keys, with composite values.
Compressing index reminders.
Nested `\csname`.
Not only exchanging expansion order but also processing order, via `\ag`.

Hard things. One can rhetorically question whether the macros have been coded in a near optimal way?[57] I'm convinced that the basic approach

> to parameterize as much as possible

is a good thing. I also believe that the modular approach to encode small pieces, with clear functional tasks, is the way to build something of a reasonable size, and to keep it readable and maintainable. Literate programming avant la lettre?

Often I needed the `\xdef` functionality, but partially expanded. As a typical example the following.
Instead of

```
\xdef\<name>{\csname\the\k\endcsname}
```

I had to use (also with `\global`)

```
\ea\let\ea\<name>\csname\the\k\endcsname
```

when I incorporated the handling of accents. Also for the non-accent case the latter is better, because it leaves the contents of $\backslash\langle name\rangle$ untouched. It is not clear to me whether the use of token variables instead, would have been better.

Exchanging the order of expansion is abundantly used in the TEXbook. In generating random words I needed to delay the storing. In that particular case—reasonable size of the wordlength—I could fruitfully made use of `\ag`. From this I learned that the use of `\ag` comes in when 'stomach' processes have to be exchanged on the fly.

A TEXfall is that `\global`, so easily used with counters and definitions, does not extend to `\newif`-s. In first instance I tried to keep track of the status of the comparison of two strings by Booleans, at an inner level. Because, I could not use them globally otherwise than adapting the `\newif` macro, I have used a counter—`\status`—instead.

Another TEXfall is that the `\body` of a loop is silently redefined when nesting loops without scope braces. This occurs for example when in a loop a macro is invoked which contains an (unbraced) inner loop in its replacement text. This is different from the TEXfall where the first (inner) `\repeat` is mistaken for the outer one. Difficulties with nesting of loops, especially to keep quantities local, have been alluded to earlier by Pittman [29].

In debugging I traced every comparison and exchange via `\immediate\write16...`-s.

In articles like this it is difficult to circumvent unwanted spaces when in horizontal mode. My solution is to do the sorting in vertical mode and when done typeset in horizontal mode. I have taken notice of Eijkhout's suggestions [11].

[56] But, alas, full of details.

[57] Indeed, because of the many ways one can encode in TEX, it is very hard, if not impossible, to decide which code is best. Perhaps we have to get used to it that programming is like life. Polymorph! Knuth experienced similar things as can be distilled from 'Always remember, however, that there's usually a simpler and better way to do something than the first way that pops into your head.' The TEXbook, p. 373. Apart from the set-up, much has been given an afterthought or two.

On the other hand in the encoding of `\seq` I had to insert an empty group after `\wofif` in order to retain the separator ␣. This insertion of the empty group was also necessary in `\redrng` when rewriting the array: not `\` but `{}` ! I also had to compensate for Southall's 'buses and weirdness'-TEX effect, about which he lectured so vividly at the 1990 SGML-TEX meeting at Groningen.

Conclusion

I believe that my macros can be of use for preparing indexes completely within TEX. In the discussion about the NTS (New Typsetting System), in [28] and [35], it is argued to think in pre- and post-processing outside of TEX. Sorting index items is neither a pre- nor a post-process. Generally it is done in between. A file with index reminders is written while TEXing the compuscript. Then external sorting and the like is done outside of TEX, and finally the typesetting of the index is done again by TEX. Now all can be done within TEX, despite the good and abundant external sorters available.

At the danger of being accused of misusing TEX as

> '. . . another American screw driver'[58]

for situations not envisioned in the design, I found that encoding a non-trivial example in TEX illustrates the power of TEX's language. But, . . . I also sadly endured TEX's negative side

> Encoding in TEX is error-prone! if not for being so unusual.

This despite of its author being the initiator of literate programming.[59]

> A discipline of TEX encoding? Absolutively!

Acknowledgements

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[58] To paraphrase Perlis.

[59] With the purpose to program like writing literature. Not only to be processed by computers, but also to be read by humans, with pleasure!

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Appendix A: Heap sort

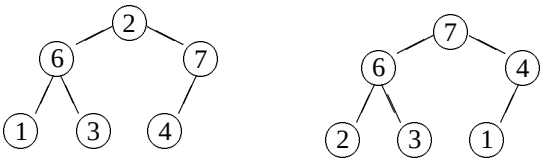
The process consists of two main steps, [2], [20]

- creation of a heap
- sorting the heap

with a sift operation to be used in both.

In comparison with my earlier release of the code in MAPS92.2, I adapted the notation with respect to sorting in *non-decreasing* order.[60]

What is a heap? A sequence $a_1, a_2, \ldots, a_n$, is a heap if $a_k \geq a_{2k} \wedge a_k \geq a_{2k+1}, k = 1, 2, \ldots, n \div 2$, and because a_{n+1} is undefined, the notation is simplified by defining $a_k > a_{n+1}, k = 1, 2, \ldots, n$.
A tree and one of its heap representations of $2, 6, 7, 1, 3, 4$ read



The algorithm. In PASCAL-like notation the algoritm, for sorting the array a[1:n], reads

%heap creation
$l := n$ **div** $2 + 1;$
while $l \neq 1$ **do**
$l := l - 1; sift(a, l, n)$ **od**
%sorting
$r := n;$
while $r \neq 1$ **do**
$(a[1], a[r]) := (a[r], a[1])\%exchange$
$r := r - 1; sift(a, 1, r)$ **od**
%sift #1 through #2
$j := \#1$
while $2j \geq \#2 \wedge (a[j] < a[2j] \vee a[j] < a[2j + 1])$ **do**
$mi := 2j +$ **if** $a[2j] > a[2j + 1]$ **then** 0 **else** 1 **fi**
$exchange(a[j], a[mi])\ j := mi$ **od**

Encoding

Purpose. Sorting values given in an array.

Input. The values are stored in the control sequences `\1`, ..., `\`$\langle n \rangle$. The counter `\n` must contain the value $\langle n \rangle$. The parameter for comparison, `\cmp`, must be `\let`-equal to `\cmpn`, for numerical comparison, to `\cmpw`, for word comparison, to `\cmpaw`, for word comparison obeying the ASCII ordering, or to a comparison macro of your own. (The latter macro variants, and in general the common definitions for `\heapsort`, and `\quicksort`, are supplied in the file `sort.tex`.)

Output. The sorted array `\1`, `\2`, ... `\`$\langle n \rangle$, with `\val1` $\leq$ `\val2` $\leq \ldots \leq$ `\val`$\langle n \rangle$.

Source

```
%heapsort.tex                          Jan, 93
\newcount\n\newcount\lc\newcount\r
\newcount\ic\newcount\uone
\newcount\jc\newcount\jj\newcount\jjone
\newif\ifgoon
%Non-descending sorting
\def\heapsort{%data in \1 to \n
\r\n\heap\ic1
{\loop\ifnum1<\r\xch\ic\r
   \advance\r-1 \sift\ic\r
\repeat}}
%
\def\heap{%Transform \1..\n into heap
 \lc\n\divide\lc2{}\advance\lc1
 {\loop\ifnum1<\lc\advance\lc-1
```

[60] It is true that the reverse of the comparison operation would do, but it seemed more consistent to me to adapt the notation of the heap concept with the smallest elements at the bottom.

```
  \sift\lc\n\repeat}}
%
\def\sift#1#2{%#1, #2 counter variables
 \jj#1\uone#2\advance\uone1 \goontrue
 {\loop\jc\jj \advance\jj\jj
  \ifnum\jj<\uone
   \jjone\jj \advance\jjone1
   \ifnum\jj<#2 \cmpval\jj\jjone
         \ifnum2=\status\jj\jjone\fi\fi
   \cmpval\jc\jj\ifnum2>\status%
                         \goonfalse\fi
 \else\goonfalse\fi
\ifgoon\xch\jc\jj\repeat}}
%
\def\cmpval#1#2{%#1, #2 counter variables
%Result: \status= 0, 1, 2 if
%values pointed by
%              #1 =, >, < #2
 \ea\let\ea\aone\csname\the#1\endcsname
 \ea\let\ea\atwo\csname\the#2\endcsname
 \cmp\aone\atwo}
\endinput                       %cgl@rug.nl
```

Explanation

\heapsort. The values given in \1,...\⟨n⟩, are sorted in non-descending order.

\heap. The values given in \1,...,\⟨n⟩, are rearranged into a heap.

\sift. The first element denoted by the first (counter) argument has disturbed the heap. Sift rearranges the part of the array denoted by its two arguments, such that the heap property holds again.

\cmpval. The values denoted by the counter values, supplied as arguments, are compared.

Examples (Numbers, words)

```
\def\1{314}\def\2{1}\def\3{27}\n3
\let\cmp\cmpn\heapsort
\begin{quote}\prtn,\end{quote}
%
\def\1{ab}\def\2{c}\def\3{aa}\n3
\let\cmp\cmpaw\heapsort
\begin{quote}\prtw,\end{quote}
and
\def\1{j\ij}\def\2{ge\"urm}\def\3{gar\c con}
\def\4{\'el\'eve}\n4
\let\cmp\cmpw {\accdef\heapsort}
\begin{quote}\prtw\end{quote}
```

yields

1, 27, 314,
aa ab c,

and

élève garçon geürm jij.

Appendix B: Quick sort

The quick sort algorithm has been discussed in many places, for example [20]. Here the following code due to Bentley [4], p. 112, has been transliterated.

```
procedure QSort(L,U)
if L<U then Swap(X[l], X[RandInt(L,U)])
   T:=X[L] M:=L
   for I:=L+1 to U do
       if X[I]<T M:=M+1
          Swap(X[M], X[I]) fi
   od Swap(X[L], X[M])
   QSort(L, M-1) QSort(M+1, U)
fi
```

Encoding

Purpose. Sorting of the values given in the array \⟨low⟩, ..., \⟨up⟩.

Input. The values are stored in \⟨low⟩, ..., \⟨up⟩, with $1 \leq low \leq up \leq n$. The parameter for comparison, \cmp, must be \let-equal to \cmpn, for number comparison, to \cmpw, for word comparison, to \cmpaw, for word comparison obeying the ASCII ordering, or to a comparison macro of your own. (The latter macros, and in general the common definitions for \heapsort, and \quicksort, are supplied in the file sort.tex.)

Output. The sorted array \⟨low⟩, ... \⟨up⟩, with \val⟨low⟩ ≤ ... ≤ \val⟨up⟩.

Source

```
%quick.tex                          Jan 93
\newcount\low\newcount\up\newcount\m
\def\quicksort{%Values given in
%\low,...,\up are sorted, non-descending.
%Parameters: \cmp, comparison.
 \ifnum\low<\up\else\brk\fi
%\refval, a reference value selected at random.
 \m\up\advance\m-\low%Size-1 of ar-
ray part
 \ifnum10<\m\rnd\multiply\m\rndval
   \divide\m99 \advance\m\low \xch\low\m
 \fi
 \ea\let\ea\refval\csname\the\low\endcsname
 \m\low\k\low\let\refvalcop\refval
 {\loop\ifnum\k<\up\advance\k1
   \ea\let\ea\oneqs\csname\the\k\endcsname
   \cmp\refval\oneqs\ifnum1=\status
      \global\advance\m1 \xch\m\k\fi
   \let\refval\refvalcop
  \repeat}\xch\low\m
 {\up\m\advance\up-1 \quicksort}%
 {\low\m\advance\low1 \quicksort}\krb}
%
\def\brk#1\krb{\fi}\def\krb{\relax}
\endinput                           %cgl@rug.nl
```

Explanation. At each level the array is partitioned into two parts. After partitioning the left part contains values less than the reference value and the right part contains values greater than or equal to the reference value. Each part is again partitioned via a recursive call of the macro. The array is sorted when all parts are partitioned.

[61] If the array is big enough. I chose rather arbitrarily 10 as threshold.

In the TEX encoding the reference value as estimate for the mean value is determined via a random selection of one of the elements.[61] Reid's [30] `\rnd` has been used. The random number is mapped into the range [low : up], via the linear transformation `\low` + (`\up` − `\low`) ∗ `\rndval`/99.[62]

The termination of the recursion is encoded in a TEX peculiar way. First, I encoded the infinite loop. Then I inserted the condition for termination with the `\fi` on the same line, and not enclosing the main part of the macro. On termination the invokation `\brk` gobbles up all the tokens at that level up to its separator `\krb`, and inserts its replacement text: a new `\fi`, to compensate for the gobbled `\fi`.

Examples (Numbers, words)

```
\def\1{314}\def\2{1}\def\3{27}\n3
\low1\up\n\let\cmp\cmpn
\quicksort
\begin{quote}\prtn,\end{quote}
%
\def\1{ab}\def\2{c}\def\3{aa}
\def\4{\ij}\def\5{ik}\def\6{z}\def\7{a}\n7
\low1\up\n\let\cmp\cmpw
\quicksort
\begin{quote}\prtw,\end{quote}
and
\def\1{j\ij}\def\2{ge\"urm}\def\3{gar\c con}
\def\4{\'el\'eve}\n4
\low1\up\n\let\cmp\cmpw
{\accdef\quicksort}
\begin{quote}\prtw.\end{quote}
```

yields

1, 27, 314,
a aa ab c ik ij z,

and

élève garçon geürm jij.

Appendix C: The file sort.tex

This file contains the common definitions of `\heapsort` and `\quicksort`, the macros for storing, the macros for sorting, the macros for typesetting, some variants for the parameter macros, and the ordering table.

```
%sort.tex                          Jan 93
%Shorthands
\let\ag=\aftergroup
\let\ea=\expandafter\let\nx=\noexpand
%Counters
\newcount\n\newcount\k\newcount\kk\n=0
\newcount\kzero%Start value in prt k-loops
\newcount\pk\newcount\pkone%Used in sortcs
\newcount\frst%First value of range
\newcount\lst %Last value of range
\newcount\slst%Successor \lst
\newcount\dif %Difference \lst-\frst
\newcount\nw  %Number of words
\newcount\nc  %Number of characters/comp
\newcount\numex %Number of exchanges
\newcount\rndval%Random number
\newcount\rndnum%Seed random generator
\newcount\rndtmp%Temporary value
\newcount\status%Status comparison
%Newif-s
\newif\ifcontinue%controls loops
\newif\iffound%locating accent cs
\newif\ifproof\prooftrue
%
%Storing: from copy
\def\seq#1\qes{\k\kzero\fifow#1 \wofif{} }
%Auxiliaries: FIFO
\def\fifow#1 {\ifx\wofif#1\n\k\wofif\fi
 \processw{#1}\fifow}
\def\wofif#1\fifow{\fi}
\def\processw#1{\advance\k1 \ea
 \gdef\csname\the\k\endcsname{#1}}
%
%Storing: from file
\newread\rec
\def\storefrom#1{%#1 is file name
 \openin\rec#1 \k\kzero \continuetrue
 \loop\ifeof\rec\continuefalse\fi
 \ifcontinue\advance\k1 \read\rec to\xyz
  \ea\let\csname\the\k\endcsname\xyz
 \repeat\advance\k-1\n\k\closein\rec}
%
%Storing: random numbers
\def\storerandomn#1{%#1 number of numbers
 \n#1\k0
 \loop\ifnum\k<\n\advance\k1 \rnd\ea
  \xdef\csname\the\k\endcsname{\the\rndval}
 \repeat}
%
%With, due to Reid, 1987
\def\rnd{\global\multiply\rndnum371
 \global\advance\rndnum1
 \ifnum\rndnum>99999
  \rndtmp\rndnum \divide\rndtmp100000
  \multiply\rndtmp100000
  \global\advance\rndnum-\rndtmp
 \fi\global\rndval\rndnum
 \global\divide\rndval1000 }
%
%Storing: random words
\def\storerandomw#1{%#1 number of words
 \n#1\nw\n\def\defarr{\ea\gdef
  \csname\the\nw\endcsname}
 {\loop\ifnum0<\nw{\ag\defarr\ag{%
   \randomword}}\advance\nw-1
 \repeat}}%end s-r-w.
%
\def\randomword{\rnd \nc\rndval
 \divide\nc15 \advance\nc2
 \loop\ifnum0<\nc\randomchar
   \advance\nc-1
 \repeat}%end r-word
%
%Random character is modified
\def\randomchar{\rnd
 \multiply\rndval29 \divide\rndval100
 \ifnum26=\rndval\rndval0 \fi
 \ifnum26<\rndval\rndval4 \fi
%Mod cgl: I \ag-ed the letter
\ea\ag\ifcase\rndval
 a\or b\or c\or d\or e\or f\or g\or h\or
 i\or j\or k\or l\or m\or n\or o\or p\or
 q\or r\or s\or t\or u\or v\or w\or x\or
 y\or z\fi}%end r-char
%
%Typeset
%Parameters: Separators
\def\sepn{, }%Number separator
```

[62] Note that the number is guaranteed within the range.

```
\def\sepw{ } %Word separator
\let\sep\sepw
%
\def\prc#1{\init{#1}\def\prc##1{%
 \ifnum\lst=##1{}\else\ifnum\slst=##1{}%
  \lst\slst\advance\slst1{}\else
  \prtfl\sepn\init{##1}\fi\fi}}
%
\def\init#1{\frst#1\lst\frst \slst\frst
   \advance\slst1 }
%
%Print range: \frst-\lst (or \lst).
\def\prtfl{\the\frst\ifnum\frst<\lst
 \advance\frst1 \ifnum\frst=\lst\sepn
 \else\nobreak--\nobreak\fi\the\lst\fi}
%
%Printing sequences
\def\prts{{\k\kzero%print \1,...\n
 \def\sep{\let\sep\sepw}%
 \loop\ifnum\k<\n\advance\k1
  \sep\csname\the\k\endcsname
 \repeat}}%end \prts
%
\let\prtw\prts
%
\def\prtn{{\k\kzero%Print number sequence
 \loop\ifnum\k<\n\advance\k1
  \ea\prc\csname\the\k\endcsname
 \repeat\prtfl}}%end \prtn
%
\def\typind#1{%#1 a def
 \ea\splittot#1.%
 \ifcase\digit\word\or
         {\tt\word}\or
  {\tt\char92\word}\or
  $\langle\hbox{\word}\rangle$\fi{}
  \pagenrs}
%
\def\splittot#1 !#2 #3.{\def\word{#1}%
  \chardef\digit#2{}\def\pagenrs{#3}}
%
\def\prtind{{\def\\{\hfil\break}\k\kzero
 \def\sep{\let\sep\sepw}%
 \loop\ifnum\k<\n\advance\k1
  \sep\ea\typind\csname\the\k\endcsname
 \repeat}}
%
%Sorting in O(nlog n)
\def\sortn{\let\cmp\cmpn\sort\prtn}
%
\def\sortaw{\let\cmp\cmpaw\sort\prtw}
%
\def\sortw{\let\cmp\cmpw{\accdef\sort}\prtw}
%
\def\sort{\heapsort}
%
%Paramaters: ij and accent string
\def\accstr{\‘\’\"\^\c}
%
\def\accdef{\def\i{i}\def\j{j}%
 \def\’##1{##1a}\def\‘##1{##1g}%
 \def\"##1{##1t}\def\^##1{##1h}%
 \def\c##1{##1c}}
%
\def\ij{ij}
%
%Sorting parameters: exchange macro
\def\xch#1#2{%#1, #2 counter variables
 \ea\let\ea\auxone\csname\the#1\endcsname
 \ea\let\ea\auxtwo\csname\the#2\endcsname
 \ea\global\ea\let\csname\the#2\endcsname
 \auxone
 \ea\global\ea\let\csname\the#1\endcsname
 \auxtwo}
%
%Sorting parameters: number comparison
\def\cmpn#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2, if
%        \val{#1} =, >, < \val{#2}
 \ifnum#1=#2\global\status0 \else
   \ifnum#1>#2\global\status1 \else
               \global\status2 \fi\fi}
%
%Parameters: comparison of words
\def\cmpw#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2, if
%        \val{#1} =, >, < \val{#2}
 \let\nxt\nxtw\cmpc#1#2}
%
\def\cmpaw#1#2{%#1, #2 are defs with as
%replacement text the words.
%Result: \status= 0, 1, 2, if
%        \val{#1} =, >, < \val{#2}
 \let\nxt\nxtaw\cmpc#1#2}
%
\def\cmpc#1#2{%#1, #2 are def-s
%Result: \status= 0, 1, 2, if
%        \val{#1} =, >, < \val{#2}
\ifproof\global\advance\nc1
        \let\aa#1\let\bb#2\fi
 \global\status0 \continuetrue
 {\loop\ifx\empty#1\continuefalse\fi
       \ifx\empty#2\continuefalse\fi
  \ifcontinue\nxt#1\nxtt\nxt#2\nxtu
             \lge\nxtt\nxtu
  \repeat}\ifnum0=\status
 \ifx\empty#1\ifx\empty#2\else
                  \global\status2 \fi
 \else\ifx\empty#2\global\status1 \fi
 \fi\fi
 \ifproof\immediate\write16{\aa
  \ifnum0=\status=\else
   \ifnum1=\status>\else
                  <\fi\fi\bb.}
 \fi%end ifproof
}
%
\def\lge#1#2{%#1 and #2 letter values
%Result: \status= 0, 1, 2, if
%             #1 =, >, <  #2.
%and \continuefalse if #1=/#2.
 \ifnum#1=#2{}\else\continuefalse
  \ifnum#1<#2\global\status2 \else
             \global\status1 \fi
 \fi}
%
\def\nxtw#1#2{\def\pop##1##2\pop{%
 \gdef#1{##2}\def\head{##1}}%head and tail
 \ea\pop#1\pop%split in head and tail
 \ea\loc\head\accstr%\head is an accent cs?
 \iffound\let\acs\head
  \ea\pop#1\pop%next head and tail
  \ea\let\ea#2\csname ot\acs\head\endcsname
 \else\ea\let\ea#2\csname ot\head\endcsname
 \fi}
%
\def\loc#1#2{\def\locate##1#1##2\end
 {\ifx\empty##2\empty\foundfalse
 \else\foundtrue\fi}\ea\locate#2.#1\end}
%
%Parameters:  for ASCII words
\def\nxtaw#1#2{%Result: value of first
%letter of string supplied in #1 is delivered
%in #2. (To be used as a number (\chardef)).
%#1, #2 are control sequences.
 \def\pop##1##2\pop{\gdef#1{##2}%
  \chardef#2‘##1{}}\ea\pop#1\pop}
%
```

```
\def\cmpir#1#2{%#1, #2 defs
%Result: \status= 0, 1, 2 if
%        \val{#1} =, >, < \val{#2}
 \ea\ea\ea\decom\ea#1\ea;#2.}
%
\def\decom#1 !#2 #3;#4 !#5 #6.{%
 \def\one{#1}\def\four{#4}\cmpaw\one\four
 \ifnum0=\status%Compare secondary keys
   \ifnum#2<#5{}\global\status2 \else
     \ifnum#2>#5{}\global\status1 \else
                %Compare tertiary keys
       \ifnum#3<#6{}\global\status2 \else
         \ifnum#3>#6{}\global\status1 \fi
       \fi
     \fi
   \fi
 \fi}
%
\def\red{%Reduction of \1,...,\n
 \k0\kk0\let\refer\empty
 \loop\ifnum\k<\n\advance\k1
  \ea\let\ea\record\csname\the\k\endcsname
  \ea\splitwn\record.%
  \ifx\refer\word%extend with number
    \ea\xdef\csname\the\kk\endcsname{%
       \csname\the\kk\endcsname, \num}%
  \else%write record to \kk
   \advance\kk1\let\refer\word\ea\global
   \ea\let\csname\the\kk\endcsname\record
  \fi
 \repeat\n\kk}
%
\def\redrng{%Reduction of \1,...,\n, with
%range representation of page numbers
 {\k1\kk0
 \ea\let\ea\record\csname\the\k\endcsname
 \ea\splitwn\record.\let\refer\word
 \let\nrs\empty\prcrng\num
 \loop\ifnum\k<\n\advance\k1
  \ea\let\ea\record\csname\the\k\endcsname
  \ea\splitwn\record.%
  \ifx\refer\word%extend \nrs with number
    \prcrng\num
  \else%write record to \kk
    \advance\kk1 \strnrs
    \ea\xdef\csname\the\kk\endcsname{\refer{}
      \nrs}\let\nrs\empty\init\num\prcrng\num
    \let\refer\word
  \fi
 \repeat\ifnum1<\n
  \advance\kk1 \strnrs
  \ea\xdef\csname\the\kk\endcsname{\word{}
    \nrs}
 \global\n\kk\fi}}
%
\def\prcrng#1{\init{#1}\def\prcrng##1{%
 \ifnum##1=\lst\else\ifnum##1=\slst
  \lst\slst\advance\slst1 \else
  \strnrs\init{##1}\fi\fi}}
%
\def\strnrs{\dif\lst\advance\dif-\frst
 \edef\nrs{\ifx\nrs\empty\else\nrs\sepn\fi
  \the\frst\ifnum0<\dif
   \ifnum1=\dif\sepn\the\lst
   \else\nobreak--\nobreak\the\lst
   \fi
  \fi}}
%
\def\splitwn#1 !#2 #3.{\def\word{#1 !#2}%
 \def\num{#3}}
%
\def\getdig#1 !#2 #3.{\def\dig{#2}}
%
\def\sortcs{\global\k0\global\pk\n
\global\pkone\pk\global\advance\pkone1
%Invariant: 1:k non-cs; pk+1:n control seq-s
\loop\global\advance\k1
\ifnum\k<\pkone
 \ea\ea\ea\getdig\csname\the\k\endcsname.%
 \if2\dig{\continuetrue
  \loop
   \ifnum\k=\pk\continuefalse
   \else\ea\ea\ea\getdig\csname\the\pk
                          \endcsname.%
    \if2\dig\else\xch\k\pk\continuefalse\fi
   \fi\global\pkone\pk\global\advance\pk-1
  \ifcontinue
  \repeat}%
 \fi
\repeat}%Result\1:\pk non-cs, \pkone:\n cs
%
%Parameters: Ordering table
\chardef\ota32 \chardef\otA32
 \chardef\otaa33 \chardef\otag33
 \chardef\otat34 \chardef\otah35
\chardef\otb39 \chardef\otB39
\chardef\otc46 \chardef\otC46
 \chardef\otcc47 \chardef\otcc47
\chardef\otd53 \chardef\otD53
\chardef\ote60 \chardef\otE60
 \chardef\otea61 \chardef\oteg62
 \chardef\otet63 \chardef\oteh64
\chardef\otf67 \chardef\otF67
\chardef\otg74 \chardef\otG74
\chardef\oth81 \chardef\otH81
\chardef\oti88 \chardef\otI88
 \chardef\otit91 \chardef\otih92
\chardef\otj95 \chardef\otJ95
 \chardef\otjt98
\chardef\otk102 \chardef\otK102
\chardef\otl109 \chardef\otL109
\chardef\otm116 \chardef\otM116
\chardef\otn123 \chardef\otN123
\chardef\oto130 \chardef\otO130
 \chardef\otoa131 \chardef\otog132
 \chardef\otot133 \chardef\otoh134
\chardef\otp137 \chardef\otP137
\chardef\otq143 \chardef\otQ143
\chardef\otr150 \chardef\otR150
\chardef\ots157 \chardef\otS157
\chardef\ott164 \chardef\otT164
\chardef\otu171 \chardef\otU171
 \chardef\otut174 \chardef\otuh175
\chardef\otv178 \chardef\otV178
\chardef\otw185 \chardef\otW185
\chardef\otx192 \chardef\otX192
\chardef\otij199 \chardef\otIJ199
\chardef\oty200 \chardef\otY200
\chardef\otz206 \chardef\otZ206
\endinput                  %cgl@rug.nl
```

Appendix D: The file sort.tst

Writing macros is one thing and testing another. I find testing software as difficult as writing a variant from scratch. For convenience I have provided my (plain) testdriver below.

The test path—Which sorting worker? Tracing on/off? How many random data?—is determined in a dialogue with TEX. Rudimentary, but useful.

```
%sort.tst                          Jan 93
%Separately needed is index.tex, as data.
\input sort.tex
\input heap.tex
```

```
\input quick.tex
\immediate\write16{Heap sort as sorter? (y/n):}
\read16 to\yesorno
\if y\yesorno Heap sort.
   \def\sort{\heapsort}
\else Quick sort.
   \def\sort{\low1\up\n\quicksort}
\fi (\number\day/\number\month/\number\year)
\immediate\write16{Proofing/Tracing? (y/n):}
\read16 to\yesorno
\if y\yesorno\prooftrue
 \nopagenumbers\tracingmacros2
\else\prooffalse
\fi

\smallskip Numbers.\par
\seq314 1 27\qes
Input: \prtn.\par
Result:\sortn.
\immediate\write16{Result: \1, \2, \3,
           ...\csname\the\n\endcsname.}

\smallskip Words (ASCII).\par
\seq a b aa ab bc bb aaa\qes
Input: \prtw.\par
Result: \sortaw.
\immediate\write16{Result: \1, \2, \3,
\4, \5, \6,...\csname\the\n\endcsname.}

\smallskip Words.\par
\seq a b aa ab bc bb aaa\qes
Input: \prtw.\par
Result: \sortw.
\immediate\write16{Result: \1, \2, \3,
\4, \5, \6 ...\csname\the\n\endcsname.}

\smallskip Accented words.\par
\def\1{z}\def\2{c}\def\3{\'a\'a}\def\4{\"ab}
\def\5{ge\"urm}\def\6{ge\"{\i}nd}
\def\7{gar\c{c}on}\def\8{a}\def\9{ge{\ij}kt}
\n=9
Input: \prtw.\par
Result: \sortw.
\immediate\write16{Result: \1, \2, \3,
           ...\csname\the\n\endcsname.}

%Test and timing: random generated elements
\smallskip Sort numbers.\par
\immediate\write16{Give seed for r-generator:}
\read16 to\seed
\immediate\write16{Give maximum of num-
bers to be
   generated:}
\read16 to\total \n\total
Seed=\seed. \rndnum\seed
\storerandomn\n \par
Input: \prtn.\par
Result: \sortn.
\immediate\write16{Result: \1, \2, \3,
           ...\csname\the\n\endcsname.}

\smallskip Sort words. \par
\immediate\write16{Give seed for r-generator:}
\read16 to\seed
\immediate\write16{Give maximum of words to be
   generated:}
\read16 to\total \n\total
Seed=\seed. \rndnum\seed
\storerandomw\n \par
Input: \prtw.\par
Result: \sortw.
\immediate\write16{Result: \1, \2, \3,
           ...\csname\the\n\endcsname.}

\smallskip Sort index reminders.\par
\storefrom{index.tex}
{\def\\{\hfil\break}\let\sepw\\
\let\cmp\cmpir\k0\kk0 \null
\hfil\vtop{\hsize2.25cm\noindent
  Data:\sepw\prtw}
\hfil\vtop{\hsize2.5cm\sort\noindent
  After sorting:\sepw\prtw}
\hfil\vtop{\hsize3.5cm\redrng\noindent
  After reduction:\sepw\prtw}
\hfil\vtop{\hsize3cm\noindent
  Typeset:\sepw\prtind.}
\immediate\write16{Index rem: \1, \2, \3,
           ...\csname\the\n\endcsname.}

\smallskip Frambach's example.\par
\def\1{wd !2 7}\def\2{wrd !1 1}
\def\3{wd !2 2}\def\4{a !1 1}
\def\5{wd !2 5}\def\6{wd !2 3}
\def\7{z !3 7}\def\8{wrd !1 5}
\def\9{wd !2 1} \n9
\let\sepw\\\null
\hfil\vtop{\hsize2cm\noindent
 Data:\sepw\prtw}
\hfil\vtop{\hsize2.5cm\sortcs\noindent
 After splitting:\sepw{\n\pk\prtw}
  \sepw\kzero\pk\prtw}
\hfil\vtop{\hsize3cm\let\cmp\cmpir
 {\low1\up\pk\quicksort}
 {\low\pkone\up\n\quicksort}\noindent
 After sorting\sepw both parts,\sepw
 and compressing:\sepw\redrng\n4 \prtw}
\hfil\vtop{\hsize3cm\noindent\n4
  Typeset:\sepw\prtind.}
}
\immediate\write16{EF's exam: \1, \2, \3,
           ...\csname\the\n\endcsname.}
\bye                          cgl@rug.nl
```

Appendix E: Contents