FIFO and LIFO sing the BLUes*

Kees van der Laan

Hunzeweg 57,
9893 PB Garnwerd, The Netherlands
`cgl@rug.nl`

September 1992

Abstract

FIFO, First-In-First-Out, and LIFO, Last-In-First-Out, are well-known techniques for handling sequences. In TeX macro writing they are abundant but are not easily recognized as such. TeX templates for FIFO and LIFO are given and their use illustrated. The relation with Knuth's `\dolist`, answer ex11.5, and `\ctest`, p.376, is given.

Keywords: FIFO, LIFO, list processing, plain TeX, education, macro writing.

1 Introduction

It started with the programming of the Tower of Hanoi in TeX, van der Laan (1992a). For printing each tower the general FIFO—First-In-First-Out[1]—approach was considered.[2] In literature (and courseware) the programming of these kind of things is done differently by each author, inhibiting intelligibility. In pursuit of Wirth (1976), TeX templates for the FIFO (and LIFO) paradigm will hopefully improve the situation.

2 FIFO

In the sequel, I will restrict the meaning of FIFO to an input stream which is processed argument-wise. FIFO can be programmed in TeX as template

```
\def\fifo#1{\ifx\ofif#1\ofif\fi\process
#1\fifo}    \def\ofif#1\fifo{\fi}
```

Printing of a tower  can be done via

```
\def\process#1{\hbox to3ex{%
\hss\vrule width#1ex height1ex\hss}}
\vbox{\baselineskip1.1ex\fifo12\ofif}
```

For the termination of the tail recursion the same TeXnique as given in the TeXbook, p.379, in the macro `\deleterightmost`, is used. This is elaborated as `\break` in Fine (1992), in relation to termination of the loop. The idea is that when `\ofif` is encountered in the input stream, all tokens in the macro up to and including `\fifo`—the start for the next level of recursion—are gobbled.[3] Because the matching `\fi` is gobbled too, this token is inserted via the replacement text of `\ofif`. This TeXnique is better than Kabelschacht's, (1987), where the token preceding the `\fi` is expanded after the `\fi` via the use of `\expandafter`. When this is applied the exchange occurs at each level in the recursion. It also better than the `\let\nxt=...` TeXnique, which is used in the TeXbook, for example in `\iterate`, p.219, because there are no assignments.

My first version had the two tokens after `\ifx` reversed—a cow flew by—and made me realize the non-commutativity of the *first level* arguments of TeX's conditionals. For example, `\ifx aa\empty...` differs from `\ifx\empty aa...`, and `\if\ab\aa...` from `\if\aa\ab...`, with `\def\aa{aa}`, `\def\ab{ab}`. In math, and in programming languages like PASCAL, the equality relation is commutative,[4] and no such thing as expansion comes in between. When not alert with respect to expansion, TeX's `\if`-s can surprise you.

The `\fifo` macro is a basic one. It allows one to proceed along a list—at least conceptually—and to apply a (user) specified process to each list element. By this approach the programming of going through a list is *separated* from the various processes to be applied to

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* Earlier versions appeared in MAPS92.1 and proceedings EuroTeX '92.
[1] See Knuth (1968), section 2.2.1.
[2] In the Tower of Hanoi article Knuth's list datastructure was finally used—TeXbook Appendix D.2—with FIFO inherent.
[3] In contrast with usual programming of the recursion start with the infinite loop, and then insert the `\if...\ofif\fi`.
[4] So are TeX's `\if`-s after expansion.

the elements.[5] It adheres to the *separation of concerns* principle, which I consider fundamental.

The input stream is processed argument-wise, with the consequence that first level braces will be gobbled. Beware! Furthermore, no outer control sequences are allowed, nor `\par`-s. The latter can be permitted via the use of `\long\def`.

A general approach—relieved from the restrictions on the input stream: *every token* is processed until `\ofif`—is given in the TEXbook answer ex11.5 (`\dolist...`) and on p.376 (`\ctest...`). After adaptation to the `\fifo` notation and to the use of macros instead of token variables, Knuth's `\dolist` comes down to

```
\def\fifo{\afterassignment\tap
\let\nxt= }
\def\tap{\ifx\nxt\ofif\ofif\fi\process
\nxt\fifo}       \def\ofif#1\fifo{\fi}
```

This general approach is indispensable for macro writers. My less general approach can do a lot already, for particular applications, as will be shown below. But, . . . beware of its limitations.

2.1 Variations

The above `\fifo` can be seen as a template for encoding tail recursion in TEX, with arguments taken from the input stream one after another. An extension is to take two arguments from the input stream at a time, with the second argument to look ahead, via

```
\def\fifo#1#2{\process#1\ifx\ofif#2
    \ofif\fi\fifo#2}
\def\ofif#1\ofif{\fi}
```

Note the systematics in the use of the parameter separator in `\ofif`.

And what about recursion without parameters? A nice example of that is a variant implementation of Knuth's `\iterate` of the `\loop`, TEXbook, p.219

```
\def\iterate{\body\else\etareti\fi%
\iterate}   \def\etareti#1\iterate{\fi}
```

(This `\iterate` contains only 5 tokens in contrast with Knuth's 11. The efficiency and the needed memory is determined by the number of tokens in `\body`, and therefore this 5 vs. 11 is not relevant.)

2.2 Variable number of parameters

TEX macros can take at most 9 parameters. The above `\fifo` macro can be seen as a macro which is relieved from that restriction. Every group, or admissible token, in the input stream after `\fifo` up to and including `\ofif`, will become an argument to the macro. When the `\ofif` token is reached, the recursion will be terminated.[6]

2.3 Unknown number of arguments

Tutelaers (1992), as mentioned by Eijkhout (1991), faced the problem of inputting a chess position. The problem is characterized by an unspecified number of positions of pieces, with for the pawn positions the identification of the pawn generally omitted. Let us denote the pieces by the capital letters K(ing), Q(ueen), B(ishop), (k)N(ight), R(ook), and P(awn), with the latter symbol default. The position on the board is indicated by a letter a, b, c, . . . , or h, followed by a number, 1, 2, . . . , or 8. Then, for example,

```
\position{Ke1, Qd1, Na1, e2, e4}
```

should entail the invocations

```
\piece{K}{e1}\piece{Q}{d1}\piece{N}{a1}
\piece{P}{e2}\piece{P}{e4}
```

This can be done by an appropriate definition of `\position`, and an adaptation of the `\fifo` template, via

```
\def\position#1{\fifo#1,\ofif,}
\def\fifo#1,{\ifx\ofif#1\ofif
\fi\process#1\relax\fifo}
\def\ofif#1\fifo{\fi}
\def\process#1#2#3{\ifx\relax#3
\piece{P}{#1#2}\else\piece#1{#2#3}\fi}
```

With the following definition (simplified in relation to Tutelaers)

```
\def\piece#1#2{ #1-#2}
```

we get K-e1 Q-d1 N-a1 P-e2 P-e4.

For an unknown number of arguments at two levels see the Nested FIFO section.

2.4 Length of string

An alternative to Knuth's macro `\getlength`, TEXbook p.219, is obtained via the use of `\fifo` with

```
\newcount\length
\def\process#1{\advance\length1 }
```

Then `\fifo aap   noot\ofif\number\length`

yields the length 7.[7]

[5] If a list has to be *created*, Knuth's list datastructure might be used, however, simplifying the execution of the list. See TEXbook Appendix D.2.

[6] Another way to circumvent the 9 parameters limitation is to associate names to the quantities to be used as arguments, let us say via def's, and to use these quantities via their names in the macro. This is Knuth's parameter mechanism and is functionally related to the so-called keyword parameter mechanism of command languages, and for example ADA.

[7] Insert `\obeyspaces` when the spaces should be counted as well.

2.5 Number of asterisks

An alternative to Knuth's `\atest`, TEXbook, p.375, for determining the number of asterisks, is obtained via `\fifo` with

```
\def\process#1{\if*#1\advance\acnt by1
\fi}\newcount\acnt
```

Then `\fifo abc*de*\ofif \number\acnt` yields the number of asterisks: 2.[8]

2.6 Vertical printing

David Salomon treats the problem of vertical printing in his courseware. Via an appropriate definition of `\process` and a suitable invocation of `\fifo` it is easily obtained.

```
\def\process#1{\hbox{#1}}
xy\vbox{\offinterlineskip\fifo abc\ofif}yx
```

yields xy a b c yx.

2.7 Delete last character of argument

Again an example due to David Salomon. It is related to `\deleterightmost`, TEXbook p.379. Effective is the following, where a second parameter for `\fifo` is introduced to look ahead, which is inserted back when starting the next recursion level

```
\def\gobblelast#1{\fifo#1\ofif}
\def\fifo#1#2{\ifx\ofif#2\ofif
   \fi#1\fifo#2}
\def\ofif#1\ofif{\fi}
```

Then `\gobblelast{aap}` will yield `aa`.

2.8 Vowels, voilà

Schwarz (1987) coined the problem to print vowels in bold face.[9] The problem can be split into two parts. First, the general part of going character by character through a string, and second, decide whether the character at hand is a vowel or not.

For the first part use `\fifo` (or Knuth's `\dolist`). For the second part, combine the vowels into a string, `aeiou`, and the problem can be reduced to the question $\langle char \rangle \in$ `aeiou`? Earlier, I used this approach in searching a card in a bridge hand, van der Laan (1990, the macro `\strip`). That was well-hidden under several piles of cards, I presume? The following encoding is related to `\ismember`, TEXbook, p.379

```
\newif\iffound
\def\loc#1#2{%locate #1 in #2
\def\locate##1#1##2\end{\ifx\empty##2%
\empty\foundfalse\else\foundtrue\fi}%
\locate#2#1\end}
```

Then `\fifo Audacious\ofif` yields **Au**d**a**c**iou**s, with

```
\def\process#1{\uppercase{\loc#1}%
{AEIOU}\iffound{\bf#1}\else#1\fi}
```

2.9 Variation

If in the invocation `\locate#2#1` a free symbol is inserted between `#2` and `#1`, then `\loc` can be used to locate substrings.[10] And because $\{string_1 \in string_2\} \wedge \{string_2 \in string_1\} \Rightarrow string_1 = string_2$, the variant can be used for the equality test for strings. See also the Multiple FIFO subsection, for general and more effective alternatives for equality tests of strings.

2.10 Processing lines

What about processing lines of text? In official, judicial, documents it is a habit to fill out lines of text with dots.[11] This can be solved by making the end-of-line character active, with the function to fill up the line. A general approach where we can `\process` the line, and not only append to it, can be based upon `\fifo`.

One can wonder, whether the purpose can't be better attained by filling up the last line of paragraphs by dots, because TEX justifies with paragraphs as units.

2.11 Processing words

What about handling a list of words? This can be achieved by modifying the `\fifo` template into a version which picks up words, `\fifow`, and to give `\processw` an appropriate function.

```
\def\fifow#1 {\ifx\ofifw#1\ofifw\fi
    \processw{#1}\ \fifow}
\def\ofifw#1\fifow{\fi}
```

2.12 Underlining words

In print it is uncommon to emphasize words by underlining. Generally another font is used, see discussion of exercise 18.26 in the TEXbook. However, now and then people ask for (poor man's) underlining of words. The following `\processw` definition underlines words picked up by `\fifow`

```
\def\processw#1{\vtop{\hbox{\strut#1}
               \hrule}}
```

[8] As the reader should realize, this works correctly when there are first level asterisks *only*. For counting at all levels automatically, a more general approach is needed, see Knuth's `\ctest`, p.376.

[9] His solution mixes up the picking up of list elements and the process to be applied. Moreover, his nesting of `\if`-s in order to determine whether a character is a vowel or not, is not elegant. Fine (1992)'s solution, via a switch, is not elegant either.

[10] Think of finding 'bb' in 'ab' for example, which goes wrong without the extra symbol.

[11] The problem was posed at EuroTEX '91 by Theo Jurriens.

Then

```
\leavevmode\fifow leentje leerde lotje
lopen langs de lange lindenlaan \ofifw
\unskip.
```

yields leentje leerde lotje lopen langs de lange lindenlaan.

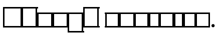
3 Nested FIFO

One can nest the FIFO paradigm. For processing lines word by word, or words character by character.

3.1 Words character by character

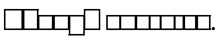
Ex11.5, can be solved by processing words character by character. A solution to a slightly simplified version of the exercise reads

```
\fifow Though  exercise \ofifw \unskip.
%with
\def\processw#1{\fifo#1\ofif}
\def\process#1{\boxit#1}
\def\boxit#1{\setbox0=\hbox{#1}\hbox
{\lower\dp0\vbox{\offinterlineskip\hrule
\hbox{\vrule\phantom#1\vrule}\hrule}}}
```

yields .

In the spirit of `\dolist...`, ex11.5, is

```
%variant neglecting word structure
\def\fifo{\afterassignment\tap
\let\nxt= }
\def\tap{\ifx\nxt\ofif\ofif
    \fi\process\nxt\fifo}
\def\ofif#1\fifo{\fi}
\def\process#1{\if\space\nxt\
\else\boxit#1\fi}
\fifo Though    exercise\ofif.
```

with the same result .

3.2 Mark up natural data

Data for `\h(v)align` needs & and `\cr` marks. We can get plain TEX to append a `\cr` at each (natural) input line, TEXbook p.249. An extension of this is to get plain TEX to insert `\cs`-s, column separators, and `\rs`-s, row separators, and eventually to add `\lr`, last row, at the end, in natural data. For example prior to an invocation of `\halign`, one wants to get plain TEX to do the transformation

P*ON
DEK* ⇒ P\cs*\csO\csN\rsD\csE\csK\cs*\lr

This can be done via

```
$$\vcenter{\hbox{P*ON}\kern.5ex
  \hbox{DEK*}} \,\Rightarrow\,
%And now right, mark up part
\bdata P*ON
DEK*
\edata\markup\data
\vcenter{\hbox{\data}}$$
```

with

```
\def\bdata{\bgroup\obeylines\store}
\def\store#1\edata{\egroup\def\data{#1}}
\def\markup#1{\ea\xdef\ea#1\ea{\ea
              \fifol#1\ofifl}}
```

and auxiliaries

```
\let\nx=\noexpand
{\catcode`\^^M=13
\gdef\fifol#1^^M#2{\fifo#1\ofif%
   \ifx\ofifl#2\nx\lr\ofifl
   \fi\nx\rs\fifol#2}}
\def\ofifl#1\ofifl{\fi}
\def\fifo#1#2{#1\ifx\ofif#2\ofif
    \fi\nx\cs\fifo#2}
\def\ofif#1\ofif{\fi}
%with for this example
\def\cs{{\sevenrm{\tt\char92}cs}}
\def\rs{{\sevenrm{\tt\char92}rs}}
\def\lr{{\sevenrm{\tt\char92}lr}}
```

The above came to mind when typesetting crosswords,[12] van der Laan (1992b), while striving after the possibility to allow natural input, independent of `\halign` processing.

4 Multiple FIFO

What about FIFO for more than one stream? (For simplicity the streams are stored in def-s, because `\read` inputs lines.) For example comparing strings, either for equality or with respect to lexicographic ordering? Eijkhout (1992, p.137, 138) provided for these applications the macros

`\ifAllChars...\Are...\TheSame`,

and

`\ifallchars...\are...\bfore`.

The encodings are focused at mouth processing. The latter contains many `\expandafter`-s.

A basic approach is: loop through the strings character by character, and compare the characters until either the assumed condition is no longer true, or the end of either one of the strings, has been reached.

[12] With *, or ⊔, given an appropriate function.

4.1 Equality of strings

The TEX-specific encoding, where use has been made of the property of `\ifx` for control sequences, reads

```
\def\eq#1#2{\def\st{#1}\def\nd{#2}
\ifx\st\nd\eqtrue\else\eqfalse\fi}
```

with auxiliary `\newif\ifeq`.

As a stepping stone for lexicographic comparison, consider the general encoding

```
\def\eq#1#2{\continuetrue\eqtrue
\loop\ifx#1\empty\continuefalse\fi
     \ifx#2\empty\continuefalse\fi
\ifcontinue \nxte#1\nxtt \nxte#2\nxtu
     \ifx\nxtt\nxtu
     \else\eqfalse\continuefalse\fi
\repeat
\ifx\empty#1\ifx\empty#2
\else\eqfalse\fi\else\eqfalse\fi}
```

with auxiliaries

```
\newif\ifcontinue\newif\ifeq
\def\nxte#1#2{\def\pop##1##2\pop{%
\gdef#1{##2}\gdef#2{##1}}\ea\pop#1\pop}
```

Then

```
\def\t{abc}\def\u{ab}
\eq\t\u\ifeq$abc=ab$\else$abc\not=ab$\fi
```

yields $abc \neq ab$.

4.2 Lexicographic comparison

Assume that we deal with lower case and upper case letters only. The encoding of `\sle`—String Less or Equal—follows the same flow as the equality test, `\eq`, but differs in the test, because of TEX's expansion mechanisms

```
\def\sle#1#2{%#1, #2 are def's
\global\sletrue {\continuetrue
\loop\ifx#1\empty\continuefalse\fi
     \ifx#2\empty\continuefalse\fi
\ifcontinue\nxte#1\nxtt\nxte#2\nxtu
     \ea\ea\ea\lle\ea\nxtt\nxtu
\repeat}
\ifsle\ifx\empty#2\ifx\empty#1
      \else\global\sltfalse\fi\fi
\fi}
```

with auxiliaries (lle=Letter Less or Equal)

```
\newif\ifcontinue\global\newif\ifsle
\def\nxte#1#2{\def\pop##1##2\pop{%
\xdef#1{##2}\xdef#2{##1}}\ea\pop#1\pop}
\def\lle#1#2{\uppercase{\ifnum`#1=`#2}
\else\continuefalse
     \uppercase{\ifnum`#1>`#2}{}\global
                     \slefalse\fi
\fi}
```

For example

```
\def\t{ABC}\def\u{ab}\sle\t\u
\ifsle$ABC<ab$\else$ABC>ab$\fi
```

yields $ABC > ab$,
and

```
\def\t{noo}\def\u{apen}\sle\t\u
\ifsle$noo<apen$\else$noo>apen$\fi
```

yields $noo > apen$.

The above can be elaborated with respect to `\read` for strings each on a separate file, to strings with accented letters, to the inclusion of an ordering table, and in general to sorting. Some of the mentioned items will be treated in Sorting in BLUe.

5 LIFO

A modification of the `\fifo` macro—`\process{#1}` invoked at the end instead of at the beginning—will yield the Last-In-First-Out template. Of course LIFO can be applied to reversion 'on the fly,' without explicitly allocating auxiliary storage.[13]

```
\def\lifo#1#2\ofil{\ifx\empty#2
  \empty\ofil\fi\lifo#2\ofil\process#1}
\def\ofil#1\ofil{\fi}
```

With the identity—`\def\process#1{#1}`, or the invoke `\process#1` replaced by `#1`[14]—the template can be used for reversion on the fly For example `\lifo aap\ofil` yields `paa`.

5.1 Change of radix

In the TEXbook a LIFO exercise is provided at p.219: print the digits of a number in radix 16 representation. The encoding is based upon the property

$$(N \div r^k) \bmod r = d_k, \quad k = 0, 1, \ldots, n,$$

with radix r, coefficients d_k, and the number representation

$$N = \sum_{k=0}^{n} d_k\, r^k.$$

[13] Johannes Braams drew my attention to Knuth and MacKay (1987), which contained among others `\reflect...\tcelfer`. They compare #1 with `\empty`, which is nice. The invocation needs an extra token, `\empty`—a so-called sentinel, see Wirth (1976)—to be included before `\tcelfer`, however. (Knuth and Mackay hide this by another macro which invokes `\reflect...\empty\tcelfer`). My approach requires at least one argument, with the consequence that the empty case must be treated separately, or a sentinel must be appended after all.

[14] Remember the stack size limitations.

There are two ways of generating the numbers d_k: starting with d_n, or the simpler one starting with d_0, with the disadvantage that the numbers are generated in reverse order with respect to printing. The latter approach is given in TEXbook p.219. Adaptation of the LIFO template does not provide a solution much different from Knuth's, because the numbers to be typeset are generated in the recursion and not available in the input stream.

6 Acknowledgements

Włodek Bzyl and Nelson Beebe are kindly acknowledged for their help in clearing up the contents and correcting my use of English, respectively.

7 Conclusion

In looking for a fundamental approach to process elements sequentially—not to confuse with list processing where the list is also built up, see TEXbook Appendix D.2, or with processing of *every* token in the input stream, see ex11.5 or p.376—TEX templates for FIFO and LIFO, emerged.

The templates can be used for processing lines, words or characters. Also processing of words line by line, or characters word by word, can be handled via nested use of the FIFO principle.

The FIFO principle along with the look ahead mechanism is applied to molding natural data into representations required by subsequent TEX processing.

Courseware might benefit from the FIFO approach to unify answers of the exercises of the macro chapter.

TEX's `\ifx...` and `\if...` conditionals are non-commutative with respect to their *first level* operands, while the similar mathematical operations are, as are the operations in current high-level programming languages.

Multiple FIFO, by comparing strings lexicographically, has been touched upon.

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