# PATtern GENeration program for the TEX82 hyphenator

(Version 2.4, April 2020)

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>The character set</td>
<td>12</td>
</tr>
<tr>
<td>Data structures</td>
<td>26</td>
</tr>
<tr>
<td>Routines for pattern trie</td>
<td>33</td>
</tr>
<tr>
<td>Routines for pattern count trie</td>
<td>43</td>
</tr>
<tr>
<td>Input and output</td>
<td>51</td>
</tr>
<tr>
<td>Routines for traversing pattern tries</td>
<td>64</td>
</tr>
<tr>
<td>Dictionary processing routines</td>
<td>74</td>
</tr>
<tr>
<td>Reading patterns</td>
<td>90</td>
</tr>
<tr>
<td>The main program</td>
<td>94</td>
</tr>
<tr>
<td>System-dependent changes</td>
<td>98</td>
</tr>
<tr>
<td>Index</td>
<td>99</td>
</tr>
</tbody>
</table>
1. Introduction. This program takes a list of hyphenated words and generates a set of patterns that can be used by the \TeX82 hyphenation algorithm.

The patterns consist of strings of letters and digits, where a digit indicates a ‘hyphenation value’ for some intercharacter position. For example, the pattern 3t2ion specifies that if the string tion occurs in a word, we should assign a hyphenation value of 3 to the position immediately before the t, and a value of 2 to the position between the t and the i.

To hyphenate a word, we find all patterns that match within the word and determine the hyphenation values for each intercharacter position. If more than one pattern applies to a given position, we take the maximum of the values specified (i.e., the higher value takes priority). If the resulting hyphenation value is odd, this position is a feasible breakpoint; if the value is even or if no value has been specified, we are not allowed to break at this position.

In order to find quickly the patterns that match in a given word and to compute the associated hyphenation values, the patterns generated by this program are compiled by \texttt{INITEX} into a compact version of a finite state machine. For further details, see the \TeX82 source.

The \texttt{banner} string defined here should be changed whenever \texttt{PATGEN} gets modified.

\begin{verbatim}
define banner \equiv \texttt{"This is PATGEN, Version 2.4"} \{ printed when the program starts \}
\end{verbatim}

2. The original version 1 of \texttt{PATGEN} was written by Frank M. Liang in 1982; a major revision (version 2) by Peter Breitenlohner in 1991 is mostly related to the new features of ‘8-bit \TeX’ (version 3 of \TeX82). The differences between versions 1 and 2 fall into several categories (all of Liang’s algorithms have been left essentially unchanged): (1) enhancements related to 8-bit \TeX, e.g., the introduction of 8-bit \texttt{ASCII} values and of \texttt{\textbackslash lefthyphenmin} and \texttt{\textbackslash righthyphenmin}; (2) a modification of the input and output procedures which should make language specific modifications of this program unnecessary (information about the external representation of all ‘letters’ used by a particular language is obtained from the \texttt{translate} file); (3) removal of ANSI standard Pascal and range check violations; (4) removal of uninitialized variables; (5) minor modifications in order to simplify system-dependent modifications.

3. This program is written in standard Pascal, except where it is necessary to use extensions. All places where nonstandard constructions are used have been listed in the index under “system dependencies.”

The program uses Pascal’s standard \texttt{input} and \texttt{output} files to read from and write to the user’s terminal.

\begin{verbatim}
define print (#) \equiv \texttt{write(output, #)}
define print_ln (#) \equiv \texttt{writeLn(output, #)}
define get_input (#) \equiv \texttt{read(input, #)}
define get_input Ln (#) \equiv
begin if eoln (input) then \texttt{readLn(input)};
\texttt{read(input, #)};
end

define end_of_PATGEN = 9999
\end{verbatim}

(Compiler directives 11)

\begin{verbatim}
program PATGEN(dictionary, patterns, translate, patout);
label end_of_PATGEN;
const \{ Constants in the outer block 27 \}
type \{ Types in the outer block 12 \}
var \{ Globals in the outer block 4 \}
procedure initialize; \{ this procedure gets things started properly \}
\begin{verbatim}
\texttt{local variables for initialization 15 \}
\end{verbatim}
begin printLn(banner);
\{ Set initial values 14 \}
\end;
4. The patterns are generated in a series of sequential passes through the dictionary. In each pass, we collect count statistics for a particular type of pattern, taking into account the effect of patterns chosen in previous passes. At the end of a pass, the counts are examined and new patterns are selected.

Patterns are chosen one level at a time, in order of increasing hyphenation value. In the sample run shown below, the parameters `hyph_start` and `hyph_finish` specify the first and last levels, respectively, to be generated.

Patterns at each level are chosen in order of increasing pattern length (usually starting with length 2). This is controlled by the parameters `pat_start` and `pat_finish` specified at the beginning of each level.

Furthermore patterns of the same length applying to different intercharacter positions are chosen in separate passes through the dictionary. Since patterns of length $n$ may apply to $n + 1$ different positions, choosing a set of patterns of lengths 2 through $n$ for a given level requires $(n+1)(n+2)/2 - 3$ passes through the word list.

At each level, the selection of patterns is controlled by the three parameters `good_wt`, `bad_wt`, and `thresh`. A hyphenating pattern will be selected if \( \text{good} \times \text{good_wt} - \text{bad} \times \text{bad_wt} \geq \text{thresh} \), where `good` and `bad` are the number of times the pattern could and could not be hyphenated, respectively, at a particular point. For inhibiting patterns, `good` is the number of errors inhibited, and `bad` is the number of previously found hyphens inhibited.

\[
\text{(Globals in the outer block 4) } \equiv \\
\text{pat_start, pat_finish: dot_type;}
\text{hyph_start, hyph_finish: val_type;}
\text{good_wt, bad_wt, thresh: integer;}
\]

See also sections 16, 23, 25, 30, 31, 33, 40, 43, 51, 52, 55, 66, 74, 78, 84, 87, 91, and 95.

This code is used in section 3.
48  INTRODUCTION

5. The proper choice of the parameters to achieve a desired degree of hyphenation is discussed in Chapter 4. Below we show part of a sample run of PATGEN, with the user’s inputs underlined.

```
ex patgen
DICTIONARY : murray.hyf
PATTERNS : nul:
TRANSLATE : nul:
PATOUT : murray.pat

This is PATGEN, Version 2.0
left_hyphen_min = 2, right_hyphen_min = 3, 26 letters
0 patterns read in
pattern trie has 256 nodes, trie_max = 256, 0 outputs
hyph_start, hyph_finish: 1 1
pat_start, pat_finish: 2 3
good weight, bad weight, threshold: 1 3 3
processing dictionary with pat_len = 2, pat_dot = 1

0 good, 0 bad, 3265 missed
0.00 %, 0.00 %, 100.00 %
338 patterns, 466 nodes in count trie, trie_max = 983
46 good and 152 bad patterns added (more to come)
finding 715 good and 62 bad hyphens, efficiency = 10.72
pattern trie has 326 nodes, trie_max = 509, 2 outputs
processing dictionary with pat_len = 2, pat_dot = 0

...  

1592 nodes and 39 outputs deleted
total of 220 patterns at hyph_level 1
hyphenate word list? y
writing pattmp.1

2529 good, 243 bad, 736 missed
77.46 %, 7.44 %, 22.54 %
```

6. Note that before beginning a pattern selection run, a file of existing patterns may be read in. In order for pattern selection to work properly, this file should only contain patterns with hyphenation values less than \textit{hyph}\_start. Each word in the dictionary is hyphenated according to the existing set of patterns (including those chosen on previous passes of the current run) before pattern statistics are collected.

Also, a hyphenated word list may be written out at the end of a run. This list can be read back in as the ‘dictionary’ to continue pattern selection from this point. In addition to ordinary hyphens (\textasciitilde `\textasciitilde`) the new list will contain two additional kinds of “hyphens” between letters, namely hyphens that have been found by previously generated patterns, as well as erroneous hyphens that have been inserted by those patterns. These are represented by the symbols \textasciitilde `\textasciitilde`, `\textasciitilde`, and `\textasciitilde`, respectively. The three characters \textasciitilde`, `\textasciitilde`, and `\textasciitilde` are, in fact, just the default values used to represent the three kinds of hyphens, the \textit{translate} file may specify different characters to be used instead of them.

In addition, a word list can include hyphen weights, both for entire words and for individual hyphen positions. (The syntax for this is explained in the dictionary processing routines.) Thus common words can be weighted more heavily, or, more generally, words can be weighted according to their frequency of occurrence, if such information is available. The use of hyphen weights combined with an appropriate setting of the pattern selection threshold can be used to guarantee hyphenation of certain words or certain hyphen positions within a word.
7. Below we show the first few lines of a typical word list, before and after generating a level of patterns.

\[
\begin{align*}
\text{abil-i-ty} & \quad \text{abil*i*ty} \\
\text{ab-sence} & \quad \text{ab*sence} \\
\text{ab-stract} & \quad \text{ab*stract} \\
\text{ac-a-dem-ic} & \quad \text{ac-a-d.em-ic} \\
\text{ac-cept} & \quad \text{ac*cept} \\
\text{ac-cept-able} & \quad \text{ac*cept-able} \\
\text{ac-cept-ed} & \quad \text{ac*cept*ed}
\end{align*}
\]

8. We augment Pascal’s control structures a bit using \texttt{goto}’s and the following symbolic labels.

\begin{verbatim}
define exit = 10  { go here to leave a procedure }
define continue = 22 { go here to resume a loop }
define done = 30   { go here to exit a loop }
define found = 40  { go here when you’ve found it }
define not_found = 41 { go here when you’ve found something else }
\end{verbatim}

9. Here are some macros for common programming idioms.

\begin{verbatim}
define incr (#) ≡ # ← # + 1  { increase a variable by unity }
define decr (#) ≡ # ← # − 1  { decrease a variable by unity }
define Incr_Decr_end(#) ≡ #
define Incr(#) ≡ # ← # + Incr_Decr_end  { we use Incr(a)(b) to increase ... }
define Decr(#) ≡ # ← # − Incr_Decr_end
  { ... and Decr(a)(b) to decrease variable a by b; this can be optimized for some compilers }
define loop ≡ while true do  { repeat over and over until a goto happens }
define do_nothing ≡ { empty statement }
define return ≡ goto exit   { terminate a procedure call }
define format return ≡ nil
#define format loop ≡ xclause
\end{verbatim}

10. In case of serious problems \texttt{PATGEN} will give up, after issuing an error message about what caused the error. Such errors might be discovered inside of subroutines inside of subroutines, so a \texttt{WEB} macro called \texttt{jump_out} has been introduced. This macro, which transfers control to the label \texttt{end_of_PATGEN} at the end of the program, contains the only non-local \texttt{goto} statement in \texttt{PATGEN}. Some Pascal compilers do not implement non-local \texttt{goto} statements. In such cases the \texttt{goto end_of_PATGEN} in the definition of \texttt{jump_out} should simply be replaced by a call on some system procedure that quietly terminates the program.

An overflow stop occurs if \texttt{PATGEN}’s tables aren’t large enough.

\begin{verbatim}
define jump_out ≡ goto end_of_PATGEN  { terminates PATGEN }
define error(#) ≡ begin print ln(#); jump_out; end
#define overflow(#) ≡ error(´PATGEN_capacity exceeded, sorry[´, #, ´].´)
\end{verbatim}

11. \langle Compiler directives 11 \rangle ≡
\begin{verbatim}
@{@&$C−, A+, D−@}  { no range check, catch arithmetic overflow, no debug overhead }
\end{verbatim}

This code is used in section 3.
12. The character set. Since different Pascal systems may use different character sets, we use the name \texttt{text.char} to stand for the data type of characters appearing in external text files. We also assume that \texttt{text.char} consists of the elements \texttt{chr(first_text_char)} through \texttt{chr(last_text_char)}, inclusive. The definitions below should be adjusted if necessary.

Internally, characters will be represented using the type \texttt{ASCII.code}. Note, however, that only some of the standard ASCII characters are assigned a fixed \texttt{ASCII.code}; all other characters are assigned an \texttt{ASCII.code} dynamically when they are first read from the translate file specifying the external representation of the ‘letters’ used by a particular language. For the sake of generality the standard version of this program allows for 256 different \texttt{ASCII.code} values, but 128 of them would probably suffice for all practical purposes.

\begin{verbatim}
define first_text_char = 0  \{ ordinal number of the smallest element of text_char \}
define last_text_char = 255 \{ ordinal number of the largest element of text_char \}
define last ASCII code = 255 \{ the highest allowed ASCII code value \}
\end{verbatim}

\begin{verbatim}
⟨Types in the outer block 12⟩≡
text_char = char; \{ the data type of characters in text files \}
ASCII_code = 0 . . last.ASCII_code; \{ internal representation of input characters \}
text_file = text;
\end{verbatim}

See also sections 13, 20, 22, and 29.

This code is used in section 3.

13. Some Pascals can store only signed eight-bit quantities (−128 . . 127) but not unsigned ones (0 . . 255) in one byte. If storage is tight we must, for such Pascals, either restrict \texttt{ASCII.code} to the range 0 . . 127 (with some loss of generality) or convert between \texttt{ASCII.code} and \texttt{packed.ASCII.code} and vice versa by subtracting or adding an offset. (Or we might define \texttt{packed.ASCII.code} as \texttt{char} and use suitable typecasts for the conversion.) Only the type \texttt{packed.ASCII.code} will be used for large arrays and the \texttt{WEB} macros \texttt{si} and \texttt{so} will always be used to convert an \texttt{ASCII.code} into a \texttt{packed.ASCII.code} and vice versa.

\begin{verbatim}
define min_packed = 0 \{ change this to ‘min_packed = −128’ when necessary; and don’t forget to change the definitions of si and so below accordingly \}
define si(#) ≡ # \{ converts ASCII code to packed ASCII code \}
define so(#) ≡ # \{ converts packed ASCII code to ASCII code \}
⟨Types in the outer block 12⟩+≡
packed.ASCII_code = min_packed . . last.ASCII_code + min_packed;
\end{verbatim}

14. We want to make sure that the “constants” defined in this program satisfy all the required relations. Some of them are needed to avoid time-consuming checks while processing the dictionary and/or to prevent range check and array bound violations.

Here we check that the definitions of \texttt{ASCII.code} and \texttt{packed.ASCII.code} are consistent with those of \texttt{si} and \texttt{so}.

\begin{verbatim}
⟨Set initial values 14⟩≡
bad ← 0;
if last.ASCII_code < 127 then bad ← 1;
if (si(0) ≠ min_packed) \lor (so(min_packed) ≠ 0) then bad ← 2;
( Check the “constant” values for consistency 28 )
if bad > 0 then error(“Bad constants---case L”, bad : 1);
\end{verbatim}

See also sections 17, 18, and 24.

This code is used in section 3.
\[\text{\textbf{15. (Local variables for initialization 15)}} \equiv \]
\text{\textit{bad: integer;}}
\text{\textit{i: text_char;}}
\text{\textit{j: ASCII_code;}}

This code is used in section 3.

\[\text{\textbf{16. We convert between ASCII_code and the user’s external character set by means of arrays xord and xchr that are analogous to Pascal’s ord and chr functions.}}\]

\(\text{\textit{Globals in the outer block 4) } + \equiv\)
\text{\textit{xord: array [text_char] of ASCII_code; } \{ \text{specifies conversion of input characters} \}}
\text{\textit{xchr: array [ASCII_code] of text_char; } \{ \text{specifies conversion of output characters} \}}

\[\text{\textbf{17. The following code initializes the xchr array with some of the standard ASCII characters.}}\]

\(\text{\textit{Set initial values 14) } + \equiv}\)
\text{\textbf{for } \textit{j} \leftarrow 0 \text{ to last.ASCII_code do } xchr[j] \leftarrow \text{‘\char\textbackslash ‘;}}
\text{\textbf{xchr[‘n’] \leftarrow ‘0’; \textbf{xchr[‘1’] \leftarrow ‘1’; xchr[‘2’] \leftarrow ‘2’; \textbf{xchr[‘3’] \leftarrow ‘3’; \textbf{xchr[‘4’] \leftarrow ‘4’;}}
\text{\textbf{xchr[‘6’] \leftarrow ‘5’; \textbf{xchr[‘7’] \leftarrow ‘6’; \textbf{xchr[‘8’] \leftarrow ‘7’; \textbf{xchr[‘9’] \leftarrow ‘8’; \textbf{xchr[‘9’] \leftarrow ‘9’;}}
\text{\textbf{xchr[‘A’] \leftarrow ‘A’; xchr[‘B’] \leftarrow ‘B’; \textbf{xchr[‘C’] \leftarrow ‘C’; xchr[‘D’] \leftarrow ‘D’; xchr[‘E’] \leftarrow ‘E’;}}
\text{\textbf{xchr[‘F’] \leftarrow ‘F’; \textbf{xchr[‘G’] \leftarrow ‘G’; \textbf{xchr[‘H’] \leftarrow ‘H’; \textbf{xchr[‘I’] \leftarrow ‘I’; xchr[‘J’] \leftarrow ‘J’;}}
\text{\textbf{xchr[‘K’] \leftarrow ‘K’; \textbf{xchr[‘L’] \leftarrow ‘L’; \textbf{xchr[‘M’] \leftarrow ‘M’; \textbf{xchr[‘N’] \leftarrow ‘N’; \textbf{xchr[‘O’] \leftarrow ‘0’;}}
\text{\textbf{xchr[‘P’] \leftarrow ‘P’; \textbf{xchr[‘Q’] \leftarrow ‘Q’; \textbf{xchr[‘R’] \leftarrow ‘R’; xchr[‘S’] \leftarrow ‘S’; \textbf{xchr[‘T’] \leftarrow ‘T’;}}
\text{\textbf{xchr[‘U’] \leftarrow ‘U’; \textbf{xchr[‘V’] \leftarrow ‘V’; \textbf{xchr[‘W’] \leftarrow ‘W’; \textbf{xchr[‘X’] \leftarrow ‘X’; xchr[‘Y’] \leftarrow ‘Y’;}}
\text{\textbf{xchr[‘Z’] \leftarrow ‘Z’;}}

\[\text{\textbf{18. The following system-independent code makes the xord array contain a suitable inverse to the information in xchr.}}\]

\text{\textbf{define invalid_code = 0 } \{ \text{ASCII_code that should not appear} \}}
\text{\textbf{define tab_char = ‘11} } \{ \text{ord of tab character; tab characters seem to be unavoidable with files from UNIX systems} \}

\(\text{\textit{Set initial values 14) } + \equiv}\)
\text{\textbf{for } \textit{i} \leftarrow \text{chr(first_text_char) to chr(last_text_char) do } xord[i] \leftarrow \text{invalid_code;}}
\text{\textbf{for } \textit{j} \leftarrow 0 \text{ to last.ASCII_code do } xord[xchr[j]] \leftarrow j; xord[‘\text{‘\char\textacuted}}
\text{xord[‘\text{‘\char\textbackslash ‘] \leftarrow ‘\text{‘\char\textbackslash ‘; xord[\text{chr(tab_char)]] \leftarrow ‘\text{‘\char\textbackslash ‘;}}
19. So far each invalid ASCII code has been assigned the character `<' and all invalid characters have been assigned ASCII code = invalid_code. The get_ASCII function, used only while reading the translate file, returns the ASCII code corresponding to a character, assigning a new ASCII code first if necessary.

```plaintext
define num_ASCII_codes = last_ASCII_code + 1  { number of different ASCII code values }
function get_ASCII(c : text_char): ASCII_code;
  label found;
  var i: ASCII_code;
  begin i ← xord[c];
    if i = invalid_code then
      begin while i < last_ASCII_code do
          begin incr(i);
            if (xchr[i] = `<`) ∧ (i ≠ `"`) then goto found;
          end;
        overflow(num_ASCII_codes : 1, `<characters`);
      found: xord[c] ← i; xchr[i] ← c;
    end;
  get_ASCII ← i;
end;
```

20. The TEX82 hyphenation algorithm operates on ‘hyphenable words’ converted temporarily to lower case, i.e., they may consist of up to 255 different ‘letters’ corresponding to \lccodes 1..255. These \lccodes could, in principle, be language dependent but this might lead to undesirable results when hyphenating multilingual paragraphs. No more than 245 different letters can occur in hyphenation patterns since the characters `0`..`9` and `.` play a special rôle when reading patterns. For the purpose of this program each letter is represented internally by a unique internal_code ≥ 2 (internal_code = 1 is the edge_of_word indicator); internal_code values 2..127 will probably suffice for all practical purposes, but we allow the range 2..last_ASCII_code for the sake of generality. Syntactically internal_code and ASCII_code are the same, we will use one or the other name according to the semantic context.

```plaintext
define edge_of_word = 1  { internal_code for start and end of a word }
⟨Types in the outer block 12⟩ ≡
  internal_code = ASCII_code; packed_internal_code = packed_ASCII_code;
```
21. Note that an \textit{internal\_code} used by this program is in general quite different from the \textit{ASCII\_code} (or rather \texttt{\textbackslash lccode}) used by \TeX\n82. This program allows the input of characters (from the \textit{dictionary} and \textit{patterns} file) corresponding to an \textit{internal\_code} in either lower or upper case form; the output (to the \textit{patout} and \textit{pattmp} file) will always be in lower case form.

Unfortunately there does not (yet?) exist a standardized and widely accepted 8-bit character set (or a unique one-to-one translation between such sets). On the other hand macro expansion takes place in \TeX\n82 when reading hyphenable words and when reading patterns. Thus the lower and upper case versions of all ‘letters’ used by a particular language can (and for the sake of portability should) be represented entirely in terms of the standard ASCII character set; either directly as characters or via macros (or active characters) with or without arguments. The macro definitions for such a representation will in general be language dependent.

For the purpose of this program the external representation of the lower and upper case version of a letter (i.e., \textit{internal\_code}) consists of a unique sequence of characters (or \textit{ASCII codes}), the only restriction being that no such sequence must be a subsequence of an other one. Moreover such sequences must not start with \texttt{\textbackslash -}, \texttt{\textbackslash .}, \texttt{\textbackslash 0} \ldots \texttt{\textbackslash 9} or with one of the three characters (\texttt{\textbackslash *, \textbackslash .}, and \texttt{\textbackslash .}) representing hyphens in the \textit{dictionary} file; a sequence may, however, end with a mandatory \texttt{\textbackslash -} as, e.g., the sequence \texttt{\ss\textbackslash }.

The language dependent values of \texttt{\textbackslash lefthyphenmin} and \texttt{\textbackslash righthyphenmin} as well as the external representation of the lower and upper case letters and their collating sequence are specified in the \textit{translate} file, thus making any language dependent modifications of this program unnecessary. If the \textit{translate} file is empty (or does not exist) the values \texttt{\textbackslash lefthyphenmin=2} and \texttt{\textbackslash righthyphenmin=3} and \textit{internal\_code} values \texttt{2 \ldots 27} with the one character external representations \texttt{\textbackslash a} \ldots \texttt{\textbackslash z} and \texttt{\textbackslash A} \ldots \texttt{\textbackslash Z} will be used as defaults.

Incidentally this program can be used to convert a \textit{dictionary} and \textit{patterns} file from one (“upper case”) to another (“lower case”) external representation of letters.
22. When reading the dictionary (and patterns) file sequences of characters must be recognized and converted to their corresponding internal code. This conversion is part of PATGENs inner loop and must therefore be done as efficient as possible. Thus we will mostly bypass the conversion from character to ASCII code and convert directly to the corresponding internal code using the xclass and xint arrays. Six types of characters are distinguished by their xclass:

- space_class character `\u2000` terminates a pattern or word.
- digit_class characters `0` . . . `9` are hyphen values for a pattern or hyphen weights for a word; their xint is the corresponding numeric value 0 . . . 9.
- hyf_class characters (`\` , `\-` , and `\*`) are `dots` and indicate hyphens in a word; their xint is the corresponding numeric value err_hyf . . . found_hyf.
- letter_class characters represent a letter; their xint is the corresponding internal code.
- escape_class characters indicate the start of a multi-character sequence representing a letter.
- invalid_class characters should not occur except as part of multi-character sequences.

```plaintext
define space_class = 0 { the character `\u2000` }
define digit_class = 1 { the characters `0` . . . `9` }
define hyf_class = 2 { the `hyphen' characters (`\` , `\-` , and `\*`) }
define letter_class = 3 { characters representing a letter }
define escape_class = 4 { characters that start a multi-character sequence representing a letter }
define invalid_class = 5 { characters that normally should not occur }
define no_hyf = 0 { no hyphen }
define err_hyf = 1 { erroneous hyphen }
define is_hyf = 2 { hyphen }
define found_hyf = 3 { found hyphen }
```

(Types in the outer block 12) \equiv
class_type = space_class .. invalid_class; { class of a character }
digit = 0 .. 9; { a hyphen weight (or word weight) }
hyf_type = no_hyf .. found_hyf; { type of a hyphen }

23. In addition we will use the xext, xdig, and xdot arrays to convert from the internal representation to the corresponding characters.

```plaintext
Globals in the outer block 4) \equiv
xclass: array [text_char] of class_type; { specifies the class of a character }
xint: array [text_char] of internal_code; { specifies the internal_code for a character }
xdig: array [0 .. 9] of text_char; { specifies conversion of output characters }
xext: array [internal_code] of text_char; { specifies conversion of output characters }
xhyf: array [err_hyf .. found_hyf] of text_char; { specifies conversion of output characters }
```

24. (Set initial values 14) \equiv
for i ← chr(first_text_char) to chr(last_text_char) do
    begin xclass[i] ← invalid_class; xint[i] ← 0;
    end;
xclass[\u2000] ← space_class;
for j ← 0 to last.ASCIIII_code do xext[j] ← `\u2000`;
xext[edge_of_word] ← `\` ;
for j ← 0 to 9 do
    begin xdig[j] ← xchr[j + "0"]; xclass[xdig[j]] ← digit_class; xint[xdig[j]] ← j;
    end;
xhyf[err_hyf] ← `\` ; xhyf[is_hyf] ← `\-` ; xhyf[found_hyf] ← `\*` ;
{ default representation for hyphens }
25. We assume that words use only the letters \( \text{cmin} + 1 \) through \( \text{cmax} \). This allows us to save some time on trie operations that involve searching for packed transitions belonging to a particular state.

\[
\text{define } \text{cmin} = \text{edge_of_word } (\text{Globals in the outer block 4}) + \equiv \\
\text{cmax: internal_code; } \{ \text{largest internal_code or ASCII code} \}
\]
26. **Data structures.** The main data structure used in this program is a dynamic packed trie. In fact we use two of them, one for the set of patterns selected so far, and one for the patterns being considered in the current pass.

For a pattern \( p_1 \ldots p_k \), the information associated with that pattern is accessed by setting \( t_1 \leftarrow \text{trie} \_ \text{root} + p_1 \) and then, for \( 1 < i \leq k \), setting \( t_i \leftarrow \text{trie} \_ \text{link}(t_{i-1}) + p_i \); the pattern information is then stored in a location addressed by \( t_k \). Since all trie nodes are packed into a single array, in order to distinguish nodes belonging to different trie families, a special field is provided such that \( \text{trie} \_ \text{char}(t_i) = s_i(p_i) \) for all \( i \).

In addition the trie must support dynamic insertions and deletions. This is done by maintaining a doubly linked list of unoccupied cells and repacking trie families as necessary when insertions are made.

Each trie node consists of three fields: the character \( \text{trie} \_ \text{char} \), and the two link fields \( \text{trie} \_ \text{link} \) and \( \text{trie} \_ \text{back} \). In addition there is a separate boolean array \( \text{trie} \_ \text{base} \) used. When a node is unoccupied, \( \text{trie} \_ \text{char} = \text{min} \_ \text{packed} \) and the link fields point to the next and previous unoccupied nodes, respectively, in the doubly linked list. When a node is occupied, \( \text{trie} \_ \text{link} \) points to the next trie family, and \( \text{trie} \_ \text{back} \) (renamed \( \text{trie} \_ \text{outp} \)) contains the output associated with this transition. The \( \text{trie} \_ \text{base} \) bit indicates that some family has been packed at this base location, and is used to prevent two families from being packed at the same location.

27. The sizes of the pattern tries may have to be adjusted depending on the particular application (i.e., the parameter settings and the size of the dictionary). The sizes below were sufficient to generate the original set of English \TeX\,82 hyphenation patterns (file \texttt{hyphen.tex}).

\begin{verbatim}
{Constants in the outer block 27} \equiv
trie\_size = 55000; { space for pattern trie }
triec\_size = 26000; { space for pattern count trie, must be less than trie\_size and greater than the number of occurrences of any pattern in the dictionary }
max\_ops = 4080; { size of output hash table, should be a multiple of 510 }
max\_val = 10; { maximum number of levels+1, also used to denote bad patterns }
max\_dot = 15; { maximum pattern length, also maximum length of external representation of a ‘letter’ }
max\_len = 50; { maximum word length }
max\_buf\_len = 80; { maximum length of input lines, must be at least max\_len }
\end{verbatim}

This code is used in section 3.

28. \( \langle \text{Check the “constant” values for consistency 28} \rangle \equiv \)

\begin{verbatim}
if (triec\_size < 4096) \lor (trie\_size < triec\_size) then bad \leftarrow 3;
if max\_ops > trie\_size then bad \leftarrow 4;
if max\_val > 10 then bad \leftarrow 5;
if max\_buf\_len < max\_len then bad \leftarrow 6;
\end{verbatim}

This code is used in section 14.

29. \( \langle \text{Types in the outer block 12} \rangle \equiv \)

\begin{verbatim}
q\_index = 1 \ldots \text{last} \_ \text{ASCII} \_ \text{code}; { number of transitions in a state }
val\_type = 0 \ldots \text{max} \_ \text{val}; { hyphenation values }
dot\_type = 0 \ldots \text{max} \_ \text{dot}; { dot positions }
op\_type = 0 \ldots \text{max} \_ \text{ops}; { index into output hash table }
word\_index = 0 \ldots \text{max} \_ \text{len}; { index into word }
trie\_pointer = 0 \ldots \text{trie} \_ \text{size}; trie\_pointer = 0 \ldots \text{trie} \_ \text{size};
op\_word = \text{packed record} dot: dot\_type;
val: val\_type;
op: op\_type;
end;
\end{verbatim}
30. Trie is actually stored with its components in separate packed arrays, in order to save space and time (although this depends on the computer’s word size and the size of the trie pointers).

(Globals in the outer block 4) \( \equiv \)

\( \text{trie}_c: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{packed}_\text{internal}_\text{code}; \)
\( \text{trie}_l, \text{trie}_r: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{trie}_\text{pointer}; \)
\( \text{trie}_\text{taken}: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{boolean}; \)
\( \text{trie}_c: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{packed}_\text{internal}_\text{code}; \)
\( \text{trie}_l, \text{trie}_r: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{trie}_\text{pointer}; \)
\( \text{trie}_\text{taken}: \text{packed array} \ [\text{trie}_\text{pointer}] \ \text{of} \ \text{boolean}; \)
\( \text{ops}: \text{array} \ [\text{op}_\text{type}] \ \text{of} \ \text{op}_\text{word}; \) \{ output hash table \}

31. When some trie state is being worked on, an unpacked version of the state is kept in positions 1 \( \ldots q_{\max} \) of the global arrays \( \text{trie}_q.c, \text{trie}_q.l, \text{trie}_q.r. \) The character fields need not be in any particular order.

(Globals in the outer block 4) \( \equiv \)

\( \text{trie}_q.c: \text{array} \ [q_{\text{index}}] \ \text{of} \ \text{internal}_\text{code}; \) \{ character fields of a single trie state \}
\( \text{trie}_q.l, \text{trie}_q.r: \text{array} \ [q_{\text{index}}] \ \text{of} \ \text{trie}_\text{pointer}; \) \{ link fields \}
\( q_{\max}: q_{\text{index}}; \) \{ number of transitions in an unpacked state \}
\( q_{\max}_{\text{thresh}}: q_{\text{index}}; \) \{ controls density of first-fit packing \}

32. Trie fields are accessed using the following macros.

\text{define} \ \text{trie}_\text{char}(\#) \equiv \text{trie}_c[\#] \text{define} \ \text{trie}_\text{link}(\#) \equiv \text{trie}_l[\#] \text{define} \ \text{trie}_\text{back}(\#) \equiv \text{trie}_r[\#] \text{define} \ \text{trie}_\text{outp}(\#) \equiv \text{trie}_r[\#] \text{define} \ \text{trie}_\text{base}_\text{used}(\#) \equiv \text{trie}_\text{taken}[\#] \text{define} \ \text{trie}_\text{c}(\#) \equiv \text{trie}_c[\#] \text{define} \ \text{trie}_\text{l}(\#) \equiv \text{trie}_l[\#] \text{define} \ \text{trie}_\text{r}(\#) \equiv \text{trie}_r[\#] \text{define} \ \text{trie}_\text{good}(\#) \equiv \text{trie}_r[\#] \text{define} \ \text{trie}_\text{bad}(\#) \equiv \text{trie}_r[\#] \text{define} \ \text{trie}_\text{base}_\text{used}(\#) \equiv \text{trie}_\text{taken}[\#] \text{define} \ q_{\text{char}}(\#) \equiv \text{trie}_q.c[\#] \text{define} \ q_{\text{link}}(\#) \equiv \text{trie}_q.l[\#] \text{define} \ q_{\text{back}}(\#) \equiv \text{trie}_q.r[\#] \text{define} \ q_{\text{outp}}(\#) \equiv \text{trie}_q.r[\#] \text{define} \ \text{hyf}_\text{val}(\#) \equiv \text{ops}[\#].\text{val} \text{define} \ \text{hyf}_\text{dot}(\#) \equiv \text{ops}[\#].\text{dot} \text{define} \ \text{hyf}_\text{nxt}(\#) \equiv \text{ops}[\#].\text{op} \)
33. **Routines for pattern trie.** The pattern trie holds the set of patterns chosen prior to the current pass, including bad or “hopeless” patterns at the current level that occur too few times in the dictionary to be of use. Each transition of the trie includes an output field pointing to the hyphenation information associated with this transition.

(Global in the outer block 4) +≡

$$trie_{max}$$: $$trie$$_pointer;  { maximum occupied trie node }
$$trie_{bmax}$$: $$trie$$_pointer;  { maximum base of trie family }
$$trie_{count}$$: $$trie$$_pointer;  { number of occupied trie nodes, for space usage statistics }
$$op_{count}$$: $$op$$_type;  { number of outputs in hash table }

34. Initially, the dynamic packed trie has just one state, namely the root, with all transitions present (but with null links). This is convenient because the root will never need to be repacked and also we won’t have to check that the base is nonnegative when packing other states. Moreover in many cases we need not check for a vanishing link field: if $$trie_{link}(t) = 0$$ then a subsequent test for $$trie_{char} (trie_{link}(t) + c) = si(c)$$ will always fail due to $$trie_{root} = 1$$.

**define** $$trie_{root} = 1$$

**procedure** init_pattern_trie;
**var** $$c$$: internal_code; $$h$$: $$op$$_type;
**begin** for $$c ← 0$$ to last_ASCII_code do
  **begin**$$trie_{char}(trie_{root} + c) ← si(c);$$  { indicates node occupied; fake for $$c = 0$$ }
  $$trie_{link}(trie_{root} + c) ← 0;$$ $$trie_{outp}(trie_{root} + c) ← 0;$$ $$trie_{base}_used(trie_{root} + c) ← false;$$
  **end**;
  $$trie_{base}_used(trie_{root}) ← true;$$ $$trie_{bmax} ← trie_{root};$$ $$trie_{max} ← trie_{root} + last_{ASCII}$$_code;
  $$trie_{count} ← num_{ASCII}$$_codes;
  $$qmax$$_thresh ← 5;
  $$trie_{link}(0) ← trie_{max} + 1;$$ $$trie_{back}(trie_{max} + 1) ← 0;$$
  { $$trie_{link}(0)$$ is used as the head of the doubly linked list of unoccupied cells }
**for** $$h ← 1$$ to max_ops do $$hyf_{val}(h) ← 0;$$  { clear output hash table }
  $$op_{count} ← 0;$$
**end**;

35. The **first_fit** procedure finds a hole in the packed trie into which the state in $$trieq.c$$, $$trieq.l$$, and $$trieq.r$$ will fit. This is normally done by going through the linked list of unoccupied cells and testing if the state will fit at each position. However if a state has too many transitions (and is therefore unlikely to fit among existing transitions) we don’t bother and instead just pack it immediately to the right of the occupied region (starting at $$trie_{max} + 1$$).

**function** first_fit: $$trie$$_pointer;
**label** found, not_found;
**var** $$s, t$$: $$trie$$_pointer; $$q$$: $$q$$_index;
**begin**  { Set $$s$$ to the trie base location at which this state should be packed 36 };
**for** $$q ← 1$$ to $$qmax$$ do  { pack it }
  **begin**$$t ← s + q.char(q);$$
    $$trie_{link}(trie_{back}(t)) ← trie_{link}(t);$$ $$trie_{back}(trie_{link}(t)) ← trie_{back}(t);$$  { link around filled cell }
    $$trie_{char}(t) ← si(q.char(q));$$ $$trie_{link}(t) ← q.link(q);$$ $$trie_{outp}(t) ← q.outp(q);$$
    if $$t > trie_{max}$$ then $$trie_{max} ← t;$$
  **end**;
  $$trie_{base}_used(s) ← true;$$ $$first_fit ← s$$
**end**;
36. The threshold for large states is initially 5 transitions. If more than one level of patterns is being generated, the threshold is set to 7 on subsequent levels because the pattern trie will be sparser after bad patterns are deleted (see delete_bad_patterns).

\[
\text{if } q_{\text{max}} > q_{\text{max}}_{\text{thresh}} \text{ then } t \leftarrow \text{trie.back}(\text{trie.max} + 1) \text{ else } t \leftarrow 0;
\]

\[
\text{loop}
\]

\[
\text{if } \text{trie.base.used}(s) \text{ then goto not.found;}
\]

\[
\text{for } q \leftarrow q_{\text{max}} \text{ downto } 2 \text{ do }
\]

\[
\text{if } \text{trie.char}(s + q_{\text{char}}(q)) \neq \text{min.packed} \text{ then goto not.found;}
\]

\[
\text{goto found;}
\]

\[
\text{not.found: end;}
\]

\[
\text{found: }
\]

This code is used in section 35.

37. The trie is only initialized (as a doubly linked list of empty cells) as far as necessary. Here we extend the initialization if necessary, and check for overflow.

\[
\text{if } s > \text{trie.size} - \text{num.ASCII.codes} \text{ then overflow(\text{trie.size}:1, pattern nodes);}
\]

\[
\text{while } \text{trie.bmax} < s \text{ do }
\]

\[
\text{trie.base.used}(\text{trie.bmax}) \leftarrow \text{false;}
\]

\[
\text{trie.char}(\text{trie.bmax} + \text{last.ASCII.code}) \leftarrow \text{min.packed;}
\]

\[
\text{trie.link(\text{trie.bmax} + \text{last.ASCII.code}) \leftarrow \text{trie.bmax} + \text{num.ASCII.codes;}
\]

\[
\text{trie.back(\text{trie.bmax} + \text{num.ASCII.codes}) \leftarrow \text{trie.bmax} + \text{last.ASCII.code;}
\]

This code is used in section 36.

38. The unpack procedure finds all transitions associated with the state with base \( s \), puts them into the arrays trieq_c, trieq_l, and trieq_r, and sets \( q_{\text{max}} \) to one more than the number of transitions found. Freed cells are put at the beginning of the free list.

\[
\text{procedure unpack}(s: \text{trie.pointer});
\]

\[
\text{var } c: \text{internal.code}; t: \text{trie.pointer};
\]

\[
\text{begin } q_{\text{max}} \leftarrow 1;
\]

\[
\text{for } c \leftarrow \text{cmin} \text{ to } \text{cmax} \text{ do } \{ \text{search for transitions belonging to this state} \}
\]

\[
\text{begin } t \leftarrow s + c;
\]

\[
\text{if } \text{so(trie.char}(t)) = c \text{ then } \{ \text{found one} \}
\]

\[
\text{begin } q_{\text{char}}(q_{\text{max}}) \leftarrow c; \text{q.link}(q_{\text{max}}) \leftarrow \text{trie.link}(t); \text{q.outp}(q_{\text{max}}) \leftarrow \text{trie.outp}(t); \text{incr}(q_{\text{max}});
\]

\[
\{ \text{now free trie node} \}
\]

\[
\text{trie.back(\text{trie.link}(0))} \leftarrow t; \text{trie.link}(t) \leftarrow \text{trie.link}(0); \text{trie.link}(0) \leftarrow t; \text{trie.back}(t) \leftarrow 0;
\]

\[
\text{trie.char}(t) \leftarrow \text{min.packed;}
\]

\[
\text{end;}
\]

\[
\text{trie.base.used}(s) \leftarrow \text{false;}
\]

\[
\text{end;}
\]
39. The function `new_trie_op` returns the ‘opcode’ for the output consisting of hyphenation value \( v \), hyphen position \( d \), and next output \( n \). The hash function used by `new_trie_op` is based on the idea that \( \frac{313}{510} \) is an approximation to the golden ratio [cf. *The Art of Computer Programming* 3 (1973), 510–512]; but the choice is comparatively unimportant in this particular application.

```plaintext
function new_trie_op(v : val_type; d : dot_type; n : op_type): op_type;
    label exit;
    var h: op_type;
    begin h ← ((n + 313 * d + 361 * v) mod max_ops) + 1; { trial hash location }
        loop
            begin if hyf_val(h) = 0 then  { empty position found }
                begin incr(op_count);
                    if op_count = max_ops then overflow(max_ops : 1, ´outputs´);
                        hyf_val(h) ← v; hyf_dot(h) ← d; hyf_nxt(h) ← n; new_trie_op ← h; return;
                    end;
                    if (hyf_val(h) = v) ∧ (hyf_dot(h) = d) ∧ (hyf_nxt(h) = n) then   { already in hash table }
                        begin new_trie_op ← h; return;
                    end;
                    if h > 1 then decre(h) else h ← max_ops;   { try again }
                end;
            exit: end;
        end 
    end 
```

40. ⟨Globals in the outer block 4⟩ +≡

```plaintext
pat: array [dot_type] of internal_code; { current pattern }
pat_len: dot_type; { pattern length }
```

41. Now that we have provided the necessary routines for manipulating the dynamic packed trie, here is a procedure that inserts a pattern of length \( \text{pat_len} \), stored in the `pat` array, into the pattern trie. It also adds a new output.

```plaintext
procedure insert_pattern(val : val_type; dot : dot_type);
    var i: dot_type; s, t: trie_pointer;
    begin i ← 1; s ← trie_root + pat[i]; t ← trie_link(s);
        while (t > 0) ∧ (i < pat_len) do   { follow existing trie }
            begin incr(i); Incr(t)(pat[i]);
                if so(trie_char(t)) ≠ pat[i] then   { Insert critical transition, possibly repacking 42 }
                    s ← t; t ← trie_link(s);
            end;
            q_link(1) ← 0; q_outp(1) ← 0; qmax ← 1;
        while i < pat_len do   { insert rest of pattern }
            begin incr(i); q_char(1) ← pat[i]; t ← first_fit; trie_link(s) ← t; s ← t + pat[i]; incr(trie_count);
            end;
        trie_outp(s) ← new_trie_op(val, dot, trie_outp(s));
    end;
```
§42. We have accessed a transition not in the trie. We insert it, repacking the state if necessary.

\[(\text{Insert critical transition, possibly repacking } 42) \equiv\]

\[
\text{begin if } \text{trie\_char}(t) = \text{min\_packed then}
\]

\[
\text{begin } \{ \text{we're lucky, no repacking needed} \}
\]

\[
\text{trie\_link(} \text{trie\_back}(t)\text{)} \leftarrow \text{trie\_link}(t); \text{trie\_back(} \text{trie\_link}(t)\text{)} \leftarrow \text{trie\_back}(t);
\]

\[
\text{trie\_char}(t) \leftarrow \text{si}(\text{pat}[i]); \text{trie\_link}(t) \leftarrow 0; \text{trie\_outp}(t) \leftarrow 0;
\]

\[
\text{if } t > \text{trie\_max then } \text{trie\_max} \leftarrow t;
\]

\[
\text{end}
\]

\[
\text{else begin } \{ \text{whoops, have to repack} \}
\]

\[
\text{unpack(} t - \text{pat}[i]\text{)};
\]

\[
\text{q\_char}(\text{qmax}) \leftarrow \text{pat}[i]; \text{q\_link}(\text{qmax}) \leftarrow 0; \text{q\_outp}(\text{qmax}) \leftarrow 0;
\]

\[
\text{t} \leftarrow \text{first\_fit}; \text{trie\_link}(s) \leftarrow t; \text{Incr}(t)(\text{pat}[i]);
\]

\[
\text{end};
\]

\[
\text{incr(} \text{trie\_count}\text{)};
\]

\[
\text{end}
\]

This code is used in sections 41 and 59.
43. **Routines for pattern count trie.** The pattern count trie is used to store the set of patterns considered in the current pass, along with the counts of good and bad instances. The fields of this trie are the same as the pattern trie, except that there is no output field, and leaf nodes are also used to store counts ($\texttt{triec\_good}$ and $\texttt{triec\_bad}$). Except where noted, the following routines are analogous to the pattern trie routines.

\begin{align*}
\text{(Globals in the outer block 4) } &+ \equiv \\
\text{triec\_max, triec\_bmax, triec\_count: triec\_pointer;} &\quad \{\text{same as for pattern trie}\} \\
\text{triec\_kmax: triec\_pointer;} &\quad \{\text{shows growth of trie during pass}\} \\
\text{pat\_count: integer;} &\quad \{\text{number of patterns in count trie}\}
\end{align*}

44. [See init\_pattern\_trie.] The variable $\texttt{triec\_kmax}$ always contains the size of the count trie rounded up to the next multiple of 4096, and is used to show the growth of the trie during each pass.

```plaintext
define triec\_root = 1
procedure init\_count\_trie;
var c: internal\_code;
begin for c ← 0 to last\_ASCII\_code do
begin triec\_char(triec\_root + c) ← si(c);
  triec\_link(triec\_root + c) ← 0;
  triec\_back(triec\_root + c) ← 0;
  triec\_base\_used(triec\_root + c) ← false;
end;
triec\_base\_used(triec\_root) ← true;
triec\_bmax ← triec\_root;
triec\_max ← triec\_root + last\_ASCII\_code;
triec\_count ← num\_ASCII\_codes;
triec\_kmax ← 4096;
triec\_link(0) ← triec\_max + 1;
triec\_back(triec\_max + 1) ← 0;
pat\_count ← 0;
end;
```

45. [See first\_fit.]
46. The threshold for attempting a first-fit packing is 3 transitions, which is lower than for the pattern trie because speed is more important here.

\[(\text{Set } b \text{ to the count trie base location at which this state should be packed}) \equiv\]

\[
\text{if } q_{\text{max}} > 3 \text{ then } a \leftarrow \text{triec}_{\text{back}}(\text{triec}_{\text{max}} + 1) \text{ else } a \leftarrow 0; \\
\text{loop}
\]

\[
\begin{align*}
&\text{begin } a \leftarrow \text{triec}_{\text{link}}(a); b \leftarrow a - q_{\text{char}}(1); \\
&\text{(Ensure triec linked up to } b + \text{num}_\text{ASCII}_\text{codes}) \\
&\text{if } \text{triec}_{\text{base}}_{\text{used}}(b) \text{ then goto not_found;} \\
&\text{for } q \leftarrow q_{\text{max}} \text{ downto } 2 \text{ do } \\
&\text{if } \text{triec}_{\text{char}}(b + q_{\text{char}}(q)) \neq \text{min}_\text{packed} \text{ then goto not_found;} \\
&\text{goto found}; \\
\end{align*}
\]

\[\text{not_found: end; found: end;}
\]

This code is used in section 45.

47. \[(\text{Ensure triec linked up to } b + \text{num}_\text{ASCII}_\text{codes}) \equiv\]

\[
\text{if } b > \text{triec}_{\text{kmax}} - \text{num}_\text{ASCII}_\text{codes} \text{ then} \\
\begin{align*}
&\text{begin if } \text{triec}_{\text{kmax}} = \text{triec}_{\text{size}} \text{ then overflow(\text{triec}_{\text{size}} : 1, \text{count}_\text{trie}_{\text{nodes}}); print(\text{triec}_{\text{kmax}} \text{ div } 1024 : 1, \text{K}_}\text{nodes}; \\
&\text{if } \text{triec}_{\text{kmax}} > \text{triec}_{\text{size}} - 4096 \text{ then } \text{triec}_{\text{kmax}} \leftarrow \text{triec}_{\text{size}} \\
&\text{else Incr(\text{triec}_{\text{kmax}})(4096); end; while } \text{triec}_{\text{bmax}} < b \text{ do } \\
&\text{begin incr(\text{triec}_{\text{bmax}}); \text{triec}_{\text{base}}_{\text{used}}(\text{triec}_{\text{bmax}}) \leftarrow \text{false; } \\
&\text{triec}_{\text{char}}(\text{triec}_{\text{bmax}} + \text{last}_\text{ASCII}_\text{code}) \leftarrow \text{min}_\text{packed; } \\
&\text{triec}_{\text{link}}(\text{triec}_{\text{bmax}} + \text{last}_\text{ASCII}_\text{code}) \leftarrow \text{triec}_{\text{bmax}} + \text{num}_\text{ASCII}_\text{codes}; \\
&\text{triec}_{\text{back}}(\text{triec}_{\text{bmax}} + \text{num}_\text{ASCII}_\text{codes}) \leftarrow \text{triec}_{\text{bmax}} + \text{last}_\text{ASCII}_\text{code}; \text{end}
\end{align*}
\]

This code is used in section 46.

48. [See unpack.]

\textbf{procedure unpackc}(b : \text{triec}_\text{pointer};)

\textbf{var} c : \text{internal}_\text{code}; a : \text{triec}_\text{pointer};

\textbf{begin} q_{\text{max}} \leftarrow 1;

\textbf{for} c \leftarrow \text{cmin} \text{ to } \text{cmax} \text{ do } \{ \text{search for transitions belonging to this state} \}

\textbf{begin} a \leftarrow b + c;

\textbf{if} so(\text{triec}_{\text{char}}(a)) = c \text{ then } \{ \text{found one} \}

\textbf{begin} q_{\text{char}}(q_{\text{max}}) \leftarrow c; q_{\text{link}}(q_{\text{max}}) \leftarrow \text{triec}_{\text{link}}(a); q_{\text{back}}(q_{\text{max}}) \leftarrow \text{triec}_{\text{back}}(a); \\
\text{incr}(q_{\text{max}}); \\
\text{triec}_{\text{back}}(\text{triec}_{\text{link}}(0)) \leftarrow a; \text{triec}_{\text{link}}(a) \leftarrow \text{triec}_{\text{link}}(0); \text{triec}_{\text{link}}(0) \leftarrow a; \text{triec}_{\text{back}}(a) \leftarrow 0; \\
\text{triec}_{\text{char}}(a) \leftarrow \text{min}_\text{packed}; \text{end; end;}

\text{triec}_{\text{base}}_{\text{used}}(b) \leftarrow \text{false; end;
Patterns being inserted into the count trie are always substrings of the current word, so they are contained in the array `word` with length `pat_len` and finishing position `fpos`.

```plaintext
function insertc (fpos : word_index): triec_pointer;
    var spos: word_index; a, b: triec_pointer;
    begin spos ← fpos − pat_len; { starting position of pattern }
        incr(spos); b ← trie_root + word[spos]; a ← trie_link(b);
        while (a > 0) ∧ (spos < fpos) do { follow existing trie }
            begin incr(spos); incr(a)(word[spos]);
                if so(triec_char(a)) ≠ word[spos] then { Insert critical count transition, possibly repacking 50 }
                    b ← a; a ← trie_link(a);
                end;
                q_link(1) ← 0; q_back(1) ← 0; qmax ← 1;
                while spos < fpos do { insert rest of pattern }
                    begin incr(spos); q_char(1) ← word[spos]; a ← firstc_fit; trie_link(b) ← a; b ← a + word[spos];
                        incr(triec_count);
                    end;
                insertc_pat ← b; incr (pat_count);
        end;
end;
```

50. ⟨Insert critical count transition, possibly repacking 50⟩ ≡

```plaintext
begin if trie_char(a) = min_packed then { lucky }
            begin trie_link(triec_back(a)) ← trie_link(a); trie_back(triec_link(a)) ← trie_back(a);
               trie_char(a) ← si(word[spos]); trie_link(a) ← 0; trie_back(a) ← 0;
               if a > trie_max then trie_max ← a;
            end
else begin { have to repack }
            unpackc(a − word[spos]);
            q_char(qmax) ← word[spos]; q_link(qmax) ← 0; q_back(qmax) ← 0; a ← firstc_fit; trie_link(b) ← a;
            incr(a)(word[spos]);
            end;
            incr (triec_count);
    end
```

This code is used in section 49.
51. **Input and output.** For some Pascal systems output files must be closed before the program terminates; it may also be necessary to close input files. Since standard Pascal does not provide for this, we use WEB macros and will say `close_out(f)` resp. `close_in(f)`; these macros should not produce errors or system messages, even if a file could not be opened successfully.

```pascal
define close_out(#) ≡ close(#) { close an output file }
define close_in(#) ≡ do_nothing  { close an input file }
```

(Globals in the outer block 4) +≡

`dictionary, patterns, translate, patout, pattmp: text_file;`

52. When reading a line from one of the input files (`dictionary`, `patterns`, or `translate`) the characters read from that line (padded with blanks if necessary) are to be placed into the `buf` array. Reading lines from the `dictionary` file should be as efficient as possible since this is part of PATGEN’s “inner loop”. Standard Pascal, unfortunately, does not provide for this; consequently the WEB macro `readbuf` defined below should be optimized if possible. For many Pascal’s this can be done with `readln(f, buf)` where `buf` is declared as Pascal string (i.e., as packed array `[1 .. any] of char`), for others a string type with dynamic length can be used.

```pascal
define readbuf(#) ≡ { reads a line from input file # into buf array }
begin buf_ptr ← 0;
while ¬eoln(#) do
  begin if (buf_ptr ≥ max_buf_len) then bad_input(´Line too long´);
    incr(buf_ptr); read(#, buf[buf_ptr]);
  end;
readln(#);
while buf_ptr < max_buf_len do
  begin incr(buf_ptr); buf[buf_ptr] ← ´␣´;
  end;
end
```

(Globals in the outer block 4) +≡

`buf: array [1 .. max_buf_len] of text_char;  { array to hold lines of input }
buf_ptr: 0 .. max_buf_len;  { index into buf }

53. When an error is caused by bad input data we say `bad_input(#)` in order to display the contents of the `buf` array before terminating with an error message.

```pascal
define printbuf ≡ { print contents of buf array }
begin buf_ptr ← 0;
repeat incr(buf_ptr); print(buf[buf_ptr]);
until buf_ptr = max_buf_len;
println(´␣´);
end
define bad_input(#) ≡
begin printbuf; error(#);
end
```
54. The translate file may specify the values of lefthyphenmin and righthyphenmin as well as the external representation and collating sequence of the ‘letters’ used by the language. In addition replacements may be specified for the characters ‘−’, ‘*’, and ‘.’ representing hyphens in the word list. If the translate file is empty (or does not exist) default values will be used.

procedure read_translate;
  label done;
  var c: text_char; n: integer; j: ASCII_code; bad: boolean; lower: boolean; i: dot_type;
    s,t: trie_pointer;
begin imax ← edge_of_word; reset(translate);
if eof(translate) then (Set up default character translation tables 56)
else begin
cmax ← last_ASCII_code – 1;
  while ¬eof(translate) do (Set up representation(s) for a letter 58);
end;
  close_in(translate); print_in(‘left_hyphen_min=解放军’, left_hyphen_min : 1, ‘,’, right_hyphen_min : 1, ‘,’, imax ← edge_of_word : 1, ‘,’, letters’); cmax ← imax;
end;

55. (Globals in the outer block 4) +≡
imax: internal_code;  { largest internal_code assigned so far }
left_hyphen_min, right_hyphen_min: dot_type;

56. (Set up default character translation tables 56) ≡
begin left_hyphen_min ← 2; right_hyphen_min ← 3;
for j ← "A" to "Z" do
  begin incr(imax); c ← xchr[j + "a" - "A"]
    xclass[c] ← letter_class; xint[c] ← imax;
    xext[imax] ← c; c ← xchr[j]; xclass[c] ← letter_class; xint[c] ← imax;
  end
end
This code is used in section 54.
57. The first line of the *translate* file must contain the values of \texttt{\textbackslash lefthyphenmin} and \texttt{\textbackslash righthyphenmin} in columns 1–2 and 3–4. In addition columns 5, 6, and 7 may (optionally) contain replacements for the default characters ‘.’, ‘−’, and ‘*’ respectively, representing hyphens in the word list. If the values specified for \texttt{\textbackslash lefthyphenmin} and \texttt{\textbackslash righthyphenmin} are invalid (e.g., blank) new values are read from the terminal.

\begin{verbatim}
\texttt{(Set up hyphenation data 57)} ≡
bad ← false; n ← 0;
if buf[1] = ‘\_’ then do nothing
else if xclass[buf[1]] = digit_class then n ← xint[buf[1]] else bad ← true;
if xclass[buf[2]] = digit_class then n ← 10 * n + xint[buf[2]] else bad ← true;
if (n ≥ 1) ∧ (n < max_dot) then left_hyphen_min ← n else bad ← true;
else if xclass[buf[3]] = digit_class then n ← xint[buf[3]] else bad ← true;
if (n ≥ 1) ∧ (n < max_dot) then right_hyphen_min ← n else bad ← true;
if bad then
    begin bad ← false;
    repeat print(‘left_hyphen_min, right_hyphen_min: ’); get_input(n1, n2);
        if (n1 ≥ 1) ∧ (n1 < max_dot) ∧ (n2 ≥ 1) ∧ (n2 < max_dot) then
            begin left_hyphen_min ← n1; right_hyphen_min ← n2;
        end
    else begin n1 ← 0;
        print(ln(‘Specify 1≤left_hyphen_min, right_hyphen_min≤, max_dot − 1 : 1, ‘\_’));
    end
    until n1 > 0;
end;
for j ← err_hyf to found_hyf do
    begin if buf[j + 4] ≠ ‘\_’ then xhyf[j] ← buf[j + 4];
        if xclass[xhyf[j]] = invalid_class then xclass[xhyf[j]] ← hyf_class else bad ← true;
    end;
xclass[‘.’] ← hyf_class; \{ in case the default has been changed \}
if bad then \texttt{bad_input(‘Bad hyphenation data’)}
\end{verbatim}

This code is used in section 54.
58. Each following line is either a comment or specifies the external representations for one ‘letter’ used by the language. Comment lines start with two equal characters (e.g., are blank) and are ignored. Other lines contain the external representation of the lower case version and an arbitrary number of ‘upper case versions’ of a letter preceded and separated by a delimiter and followed by two consecutive delimiters; the delimiter may be any character not occurring in either version.

(\text{Set up representation(s) for a letter 58}) \equiv
\begin{align*}
\text{begin} & \quad \text{read_buf}(\text{translate}); \quad \text{buf_ptr} \leftarrow 1; \quad \text{lower} \leftarrow \text{true}; \\
\text{while} & \quad \neg \text{bad} \quad \text{do} \quad \{ \text{lower and then upper case version} \} \\
& \quad \text{begin} \quad \text{pat_len} \leftarrow 0; \\
& \quad \text{repeat} \quad \text{if} \quad \text{buf_ptr} < \text{max.buf_len} \quad \text{then} \quad \text{incr} (\text{buf_ptr}) \quad \text{else} \quad \text{bad} \leftarrow \text{true}; \\
& \quad \quad \text{if} \quad \text{pat_len} = 0 \quad \text{then} \quad \text{goto} \quad \text{done} \\
& \quad \quad \text{else begin} \quad \text{if} \quad \text{lower} \quad \text{then} \\
& \quad \quad \quad \text{begin} \quad \text{if} \quad \text{imax} = \text{last.ASCII_code} \quad \text{then} \\
& \quad \quad \quad \quad \text{begin} \quad \text{print_buf}; \quad \text{overflow}(\text{num.ASCII.codes} : 1, \text{\textasciitilde letters}); \\
& \quad \quad \quad \quad \text{end}; \\
& \quad \quad \quad \quad \text{incr}(\text{imax}); \quad \text{xext}[\text{imax}] \leftarrow \text{chr}[\text{pat} [\text{pat_len}]]; \\
& \quad \quad \quad \quad \text{end}; \\
& \quad \quad \quad \quad \text{c} \leftarrow \text{chr}[\text{pat}[1]]; \\
& \quad \quad \quad \quad \text{if} \quad \text{pat_len} = 1 \quad \text{then} \\
& \quad \quad \quad \quad \text{begin} \quad \text{if} \quad \text{xclass}[\text{c}] \neq \text{invalid.class} \quad \text{then} \quad \text{bad} \leftarrow \text{true}; \\
& \quad \quad \quad \quad \text{xxclass}[\text{c}] \leftarrow \text{letter.class}; \quad \text{xint}[\text{c}] \leftarrow \text{imax}; \\
& \quad \quad \quad \quad \text{end} \\
& \quad \quad \quad \quad \text{else \ (Insert a letter into pattern trie 59)}; \\
& \quad \quad \quad \quad \text{end} \\
& \quad \quad \quad \quad \text{else if} \quad \text{pat_len} = \text{max.dot} \quad \text{then} \quad \text{bad} \leftarrow \text{true} \\
& \quad \quad \quad \quad \text{else begin} \quad \text{incr} (\text{pat_len}); \quad \text{pat}[\text{pat_len}] \leftarrow \text{get.ASCII}(\text{buf}[\text{buf_ptr}]); \\
& \quad \quad \quad \quad \text{end}; \\
& \quad \quad \quad \quad \text{until} \quad (\text{buf}[\text{buf_ptr}] = \text{buf}[1]) \lor \text{bad}; \\
& \quad \quad \quad \quad \text{lower} \leftarrow \text{false}; \\
& \quad \quad \quad \quad \text{end}; \\
& \quad \quad \text{done: \ if} \quad \text{bad} \quad \text{then} \quad \text{bad_input(\text{\textasciitilde Bad.representation})}; \\
& \quad \quad \text{end} \\
\end{align*}

This code is used in section 54.
59. When the (lower or upper case) external representation of a letter consists of more than one character and the corresponding ASCII values have been placed into the pat array we store them in the pattern trie. [See insert_pattern.] Since this ‘external subtrie’ starts at trie_link(trie_root) it does not interfere with normal patterns. The output field of leaf nodes contains the internal_code and the link field distinguishes between lower and upper case letters.

(Insert a letter into pattern trie 59) ≡
begin if xclass[c] = invalid_class then xclass[c] ← escape_class;
if xclass[c] ≠ escape_class then bad ← true;
i ← 0; s ← trie_root; t ← trie_link(s);
while (t > trie_root) ∧ (i < pat_len) do { follow existing trie }
    begin incr(i); Incr(t)(pat[i]);
    if so(trie_char(t)) ≠ pat[i] then ⟨Insert critical transition, possibly repacking 42⟩
    else if trie_outp(t) > 0 then bad ← true;
s ← t; t ← trie_link(s);
end;
if t > trie_root then bad ← true;
q.link(1) ← 0; q.outp(1) ← 0; qmax ← 1;
while i < pat_len do { insert rest of pattern }
    begin incr(i); q.char(1) ← pat[i]; t ← first_fit; trie_link(s) ← t; s ← t + pat[i]; incr(trie_count);
    end;
    trie_outp(s) ← imax;
if ¬lower then trie_link(s) ← trie_root;
end

This code is used in section 58.

60. The get_letter WEB macro defined here will be used in read_word and read_patterns to obtain the internal_code corresponding to a letter externally represented by a multi-character sequence (starting with an escape_class character).

define get_letter(#) ≡
begin t ← trie_root;
loop
    begin t ← trie_link(t) + xord[c];
    if so(trie_char(t)) ≠ xord[c] then bad_input(\Bad_representation\);
    if trie_outp(t) ≠ 0 then
        begin # ← trie_outp(t); goto done;
    end;
    if buf_ptr = max_buf_len then c ← \u'
else begin incr(buf_ptr); c ← buf[buf_ptr];
    end;
    end;
done: end
61. In order to prepare for the output phase we store all but the last of the ASCII codes of the external representation of each ‘lower case letter’ in the pattern count trie which is no longer used at that time. The recursive find_letters procedure traverses the ‘external subtrie’.

**procedure find_letters(b : trie_pointer; i : dot_type);**

{ traverse subtrees of family b; i is current depth in trie }

var c: ASCII_code;  { a local variable that must be saved on recursive calls }

a: trie_pointer;  { does not need to be saved }

j: dot_type;  { loop index }

l: trie_pointer;

begin if i = 1 then init_count_trie;

for c ← cmin to last_ASCII_code do  { find transitions belonging to this family }

begin a ← b + c;

if so(trie_char(a)) = c then  { found one }

begin pat[i] ← c;

if trie_outp(a) = 0 then find_letters(trie_link(a), i + 1)

else if trie_link(a) = 0 then  { this is a lower case letter }

⟨Insert external representation for a letter into count trie 62⟩;

end;

end;

end;

62. Starting from trie_root + trie_outp(a) we proceed through link fields and store all ASCII codes except the last one in the count trie; the last character has already been stored in the xext array.

⟨Insert external representation for a letter into count trie 62⟩ ≡

begin l ← trie_root + trie_outp(a);

for j ← 1 to i − 1 do

begin if trie_max = trie_size then overflow(trie_size : 1, 'count_nodes');

incr(trie_max); trie_link(l) ← trie_max; l ← trie_max; trie_char(l) ← si(pat[j]);

end;

trie_link(l) ← 0;

end

This code is used in section 61.

63. During the output phase we will say write_letter(i)(f) and write(f, xext[i]) to write the lower case external representation of the letter with internal code i to file f: xext[i] is the last character of the external representation whereas the WEB macro write_letter defined here writes all preceding characters (if any).

define write_letter-end(#) ≡

while l > 0 do

begin write(#, xchr[so(trie_char(l))]); l ← trie_link(l);

end

define write_letter(#) ≡ l ← trie_link(trie_root + #); write_letter_end
64. **Routines for traversing pattern tries.** At the end of a pass, we traverse the count trie using the following recursive procedure, selecting good and bad patterns and inserting them into the pattern trie.

```
procedure traverse_count_trie(b : trie_pointer; i : dot_type);
    { traverse subtries of family b; i is current depth in trie }
var c: internal_code;  { a local variable that must be saved on recursive calls }
a: trie_pointer;  { does not need to be saved }
begin for c ← cmin to cmax do  { find transitions belonging to this family }
    begin a ← b + c;
        if so(triec_char(a)) = c then  { found one }
            begin pat[i] ← c;
            if i < pat_len then traverse_count_trie(triec_link(a), i + 1)
            end;
        end;
    end;
end;
```

65. When we have come to the end of a pattern, `triec_good(a)` and `triec_bad(a)` contain the number of times this pattern helps or hinders the cause. We use the counts to determine if this pattern should be selected, or if it is hopeless, or if we can’t decide yet. In the latter case, we set `more_to_come` true to indicate that there might still be good patterns extending the current type of patterns.

```
(Decide what to do with this pattern 65) ≡
if good_wt * trie_good(a) < thresh then  { hopeless pattern }
    begin insert_pattern(max_val, pat_dot); incr(bad_pat_count)
    end
else if good_wt * trie_good(a) − bad_wt * trie_bad(a) ≥ thresh then  { good pattern }
    begin insert_pattern(hyph_level, pat_dot); incr(good_pat_count); incr(good_count)(triec_good(a));
    end
else more_to_come ← true
```

This code is used in section 64.

66. Some global variables are used to accumulate statistics about the performance of a pass.

```
(Globals in the outer block 4) +=
good_pat_count, bad_pat_count: integer;  { number of patterns added at end of pass }
good_count, bad_count, miss_count: integer;  { hyphen counts }
level_pattern_count: integer;  { number of good patterns at level }
more_to_come: boolean;
```
67. The recursion in traverse_count_trie is initiated by the following procedure, which also prints some statistics about the patterns chosen. The “efficiency” is an estimate of pattern effectiveness.

\[
\text{define } \text{bad_eff} \equiv (\text{thresh}/\text{good_wt})
\]

**procedure** collect_count_trie;
  begin good_pat_count \leftarrow 0; bad_pat_count \leftarrow 0; good_count \leftarrow 0; bad_count \leftarrow 0; more_to_come \leftarrow false;
  traverse_count_trie(trie_root, 1);
  print((good_pat_count : 1, \text{	extasciitilde good\textasciitilde and\textasciitilde}, bad_pat_count : 1, \text{	extasciitilde bad\textasciitilde patterns\textasciitilde added\textasciitilde});
  Incr(level_pattern_count)(good_pat_count);
  if more_to_come then print\_ln(\text{	extasciitilde more\textasciitilde to\textasciitilde come\textasciitilde}) else print\_ln(\text{	extasciitilde});
  print(\text{\textasciitilde finding\textasciitilde}, good_count : 1, \text{	extasciitilde good\textasciitilde and\textasciitilde}, bad_count : 1, \text{	extasciitilde bad\textasciitilde hyphens\textasciitilde});
  if good_pat_count \geq 0 then
    print\_ln(\text{\textasciitilde efficiency\textasciitilde \equiv \textasciitilde}, good_count/(good_pat_count + bad_count/bad_eff) : 1 : 2)
  else print\_ln(\text{\textasciitilde});
  print\_ln(\text{\textasciitilde pattern\textasciitilde trie\textasciitilde has\textasciitilde}, trie_count : 1, \text{\textasciitilde nodes\textasciitilde},
    \text{\textasciitilde trie\textasciitilde max\textasciitilde \equiv \textasciitilde}, trie_max : 1, \text{\textasciitilde outputs\textasciitilde});
  end;

68. At the end of a level, we traverse the pattern trie and delete bad patterns by removing their outputs. If no output remains, the node is also deleted.

**function** delete_patterns(s : trie_pointer): trie_pointer;
  \{ delete bad patterns in subtrie s, return 0 if entire subtrie freed, otherwise s \}
  \text{var c: internal_code; t: trie_pointer; all_freed: boolean; \{ must be saved on recursive calls \}}
  h, n: op_type; \{ do not need to be saved \}
  begin all_freed \leftarrow false;
  for c \leftarrow cmin to cmax do \{ find transitions belonging to this family \}
    begin t \leftarrow s + c;
      if so(trie\_char(t)) = c then
        begin \langle Link around bad outputs 69 \rangle;
          if trie\_link(t) > 0 then trie\_link(t) \leftarrow delete_patterns(trie\_link(t));
          if (trie\_link(t) > 0) \lor (trie\_outp(t) > 0) \lor (s = trie\_root) then all_freed \leftarrow false
        else \langle Deallocate this node 70 \rangle;
        end;
      end;
    if all_freed then \{ entire state is freed \}
      begin trie\_base_used(s) \leftarrow false; s \leftarrow 0;
    end;
  delete\_patterns \leftarrow s;
  end;

69. \langle Link around bad outputs 69 \rangle \equiv
  begin h \leftarrow 0; hyf\_nxt(0) \leftarrow trie\_outp(t); n \leftarrow hyf\_nxt(0);
    \text{while } n > 0 \text{ do}
      begin if hyf\_val(n) = max\_val then hyf\_nxt(h) \leftarrow hyf\_nxt(n)
        else h \leftarrow n;
        n \leftarrow hyf\_nxt(h);
      end;
    trie\_outp(t) \leftarrow hyf\_nxt(0);
  end
This code is used in section 68.
70. Cells freed by `delete_patterns` are put at the end of the free list.

\[
\text{(Deallocation this node) } \equiv \begin{align*}
&\text{begin } \text{trie}\_\text{link}(\text{trie}\_\text{back}(\text{trie}\_\text{max} + 1)) \leftarrow t; \ \text{trie}\_\text{back}(t) \leftarrow \text{trie}\_\text{back}(\text{trie}\_\text{max} + 1); \\
&\quad \text{trie}\_\text{link}(t) \leftarrow \text{trie}\_\text{max} + 1; \ \text{trie}\_\text{back}(\text{trie}\_\text{max} + 1) \leftarrow t; \ \text{trie}\_\text{char}(t) \leftarrow \text{min}\_\text{packed}; \\
&\quad \text{decr} (\text{trie}\_\text{count}); \\
&\text{end}
\end{align*}
\]

This code is used in section 68.

71. The recursion in `delete_patterns` is initiated by the following procedure, which also prints statistics about the number of nodes deleted, and zeros bad outputs in the hash table. Note that the hash table may become somewhat disorganized when more levels are added, but this defect isn’t serious.

\begin{verbatim}
procedure delete_bad_patterns;
  var old_op_count: op_type; old_trie_count: trie_pointer; t: trie_pointer; h: op_type;
  begin old_op_count ← op_count; old_trie_count ← trie_count;
  t ← delete_patterns(trie_root);
  for h ← 1 to max_ops do
    if hyf_val(h) = max_val then
      begin hyf_val(h) ← 0; decr(op_count);
      end;
    print ln(old_trie_count − trie_count : 1, "\_nodes\_and\_", 
    old_op_count − op_count : 1, "\_outputs\_deleted"); qmax_thresh ← 7;
    \{ pattern trie will be sparser because of deleted patterns \}
  end;
end;
\end{verbatim}

72. After all patterns have been generated, we will traverse the pattern trie and output all patterns. Note that if a pattern appears more than once, only the maximum value at each position will be output.

\begin{verbatim}
procedure output_patterns(s : trie_pointer; pat_len : dot_type);
  \{ output patterns in subtrie s; pat_len is current depth in trie \}
  var c: internal_code; \{ must be saved on recursive calls \}
    t: trie_pointer; h: op_type; d: dot_type;
    l: trie_pointer; \{ for write_letter \}
  begin for c ← cmin to cmax do
    begin t ← s + c;
      if so(trie_char(t)) = c then
        begin pat[pat_len] ← c; h ← trie_outp(t);
        if h > 0 then (Output this pattern 73);
        if trie_link(t) > 0 then output_patterns(trie_link(t), pat_len + 1);
      end;
    end;
  end;
end;
\end{verbatim}
\(\text{Output this pattern 73}\) \(\equiv\)

\begin{verbatim}
begin for \(d \leftarrow 0\) to \(\text{pat_len}\) do \(\text{hval}[d] \leftarrow 0;\)
repeat \(d \leftarrow \text{hyf\_dot}(h);\)
  if \(\text{hval}[d] < \text{hyf\_val}(h)\) then \(\text{hval}[d] \leftarrow \text{hyf\_val}(h)\);
  \(h \leftarrow \text{hyf\_nxt}(h);\)
until \(h = 0;\)
if \(\text{hval}[0] > 0\) then write(\(\text{patout}, \text{xdig}[\text{hval}[0]]\));
for \(d \leftarrow 1\) to \(\text{pat_len}\) do
  begin write\_letter(\(\text{pat}[d]\))(\(\text{patout}\)); write(\(\text{patout}, \text{xext}[\text{pat}[d]]\));
    if \(\text{hval}[d] > 0\) then write(\(\text{patout}, \text{xdig}[\text{hval}[d]]\));
  end;
write\_ln(\(\text{patout}\));
end
\end{verbatim}

This code is used in section 72.
74. Dictionary processing routines. The procedures in this section are the “inner loop” of the pattern generation process. To speed the program up, key parts of these routines could be coded in machine language.

\[
\begin{aligned}
\text{(Globals in the outer block 4) } &\equiv \\
\text{word: array [word_index] of internal_code; } &\{ \text{current word} \} \\
\text{dots: array [word_index] of hyf_type; } &\{ \text{current hyphens} \} \\
\text{dotw: array [word_index] of digit; } &\{ \text{dot weights} \} \\
\text{hval: array [word_index] of val_type; } &\{ \text{hyphenation values} \} \\
\text{no_more: array [word_index] of boolean; } &\{ \text{positions ‘knocked out’} \} \\
\text{wlen: word_index; } &\{ \text{length of current word} \} \\
\text{word wt: digit; } &\{ \text{global word weight} \} \\
\text{wt chg: boolean; } &\{ \text{indicates word wt has changed} \}
\end{aligned}
\]

75. The words in the dictionary consist of the ‘letters’ used by the language. “Dots” between letters can be one of four possibilities: ‘-’ indicating a hyphen, ‘*’ indicating a found hyphen, ‘.’ indicating an error, or nothing; these are represented internally by the four values is_hyf, found_hyf, err_hyf, and no_hyf respectively. When reading a word we will, however, convert err_hyf into no_hyf and found_hyf into is_hyf thus ignoring whether a hyphen has or has not been found by a previous set of patterns.

\[
\begin{aligned}
\text{\langle \text{Prepare to read dictionary 75} \rangle } &\equiv \\
xclass[\text{.} ] &\leftarrow \text{invalid_class;} \{ \text{in case the default has been changed} \} \\
xclass[xhyf[\text{err_hyf}]] &\leftarrow \text{hyf_class}; \text{xint}[xhyf[\text{err_hyf}]] &\leftarrow \text{no_hyf}; \text{xclass}[xhyf[\text{is_hyf}]] &\leftarrow \text{hyf_class}; \\
xint[xhyf[\text{is_hyf}]] &\leftarrow \text{is_hyf}; \text{xclass}[xhyf[\text{found_hyf}]] &\leftarrow \text{hyf_class}; \text{xint}[xhyf[\text{found_hyf}]] &\leftarrow \text{is_hyf};
\end{aligned}
\]

See also sections 79 and 85.

This code is used in section 88.
76. Furthermore single-digit word weights are allowed. A digit at the beginning of a word indicates a global word weight that is to be applied to all following words (until the next global word weight). A digit at some intercharacter position indicates a weight for that position only.

The `read_word` procedure scans a line of input representing a word, and places the letters into the array `word`, with `word[1] = word[wlen] = edge_of_word`. The dot appearing between `word[dpos]` and `word[dpos+1]` is placed in `dots[dpos]`, and the corresponding dot weight in `dotw[dpos]`.

```plaintext
procedure read_word;
    label done, found;
    var c: text_char; t: trie_pointer;
    begin read_buf(dictionary); word[1] ← edge_of_word; wlen ← 1; buf_ptr ← 0;
        repeat incr(buf_ptr); c ← buf[buf_ptr];
            case xclass[c] of
                space_class: goto found;
                digit_class: if wlen = 1 then  { global word weight }
                    begin if xint[c] ≠ word_wt then wt_chg ← true;
                        word_wt ← xint[c];
                            end
                    else dotw[wlen] ← xint[c];  { dot weight }
                hyf_class: dots[wlen] ← xint[c];  { record the dot c }
                letter_class:  { record the letter c }
                    begin incr(wlen);
                        if wlen = max_len then
                            begin print_buf; overflow(‘word|length=’, max_len : 1);
                                end;
                        word[wlen] ← xint[c]; dots[wlen] ← no_hyf; dotw[wlen] ← word_wt;
                            end;
                escape_class:  { record a multi-character sequence starting with c }
                    begin incr(wlen);
                        if wlen = max_len then
                            begin print_buf; overflow(‘word|length=’, max_len : 1);
                                end;
                        get_letter(word[wlen]); dots[wlen] ← no_hyf; dotw[wlen] ← word_wt;
                            end;
                invalid_class: bad_input(‘Bad_character’);
                    end;
            end;
        until buf_ptr = max_buf_len;
    found: incr(wlen); word[wlen] ← edge_of_word;
        end;
```
Here is a procedure that uses the existing patterns to hyphenate the current word. The hyphenation value applying between the characters \texttt{word[dpos]} and \texttt{word[dpos + 1]} is stored in \texttt{hval[dpos]}.

In addition, \texttt{no\_more[dpos]} is set to \texttt{true} if this position is "knocked out" by either a good or bad pattern at this level. That is, if the pattern with current length and hyphen position is a superstring of either a good or bad pattern at this level, then we don’t need to collect count statistics for the pattern because it can’t possibly be chosen in this pass. Thus we don’t even need to insert such patterns into the count trie, which saves a good deal of space.

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

In order to avoid unnecessary test (and range check violations) the globals \texttt{hyf\_min}, \texttt{hyf\_max}, and \texttt{hyf\_len} are set up such that only positions from \texttt{hyf\_min} up to \texttt{wlen − hyf\_max} of the \texttt{word} array need to be checked, and that words with \texttt{wlen < hyf\_len} need not to be checked at all.

\texttt{(Globals in the outer block 4) +≡ \hyf\_min, \hyf\_max, \hyf\_len: word_index;  \{} limits for legal hyphens \}}

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

\textbf{procedure hyphenate;}
\begin{verbatim}
  label done;
  var spos, dpos, fpos: word_index; t: trie_pointer; h: op_type; v: val_type;
  begin for spos ← wlen − hyf\_max downto 0 do
    begin no\_more[spos] ← false; hval[spos] ← 0; fpos ← spos + 1; t ← trie\_root + word[fpos];
      repeat h ← trie\_outp(t);
        while h > 0 do  ⟨Store output h in the hval and no\_more arrays, and advance h⟩;
          t ← trie\_link(t);
        if t = 0 then goto done;
        incr(fpos); incr(t)(word[fpos]);
      until so(trie\_char(t)) ≠ word[fpos];
  done: end;
end;
\end{verbatim}

This code is used in section 77.
81. The change_dots procedure updates the dots array representing the printing values of the hyphens. Initially, hyphens (and correctly found hyphens) in the word list are represented by is_hyf whereas non-hyphen positions (and erroneous hyphens) are represented by no_hyf. Here these values are increased by one for each hyphen found by the current patterns, thus changing no_hyf into err_hyf and is_hyf into found_hyf. The routine also collects statistics about the number of good, bad, and missed hyphens.

\[
\text{define incr_wt}(\#) \equiv \text{Incr}(\#)(\text{dotw}[dpos])
\]

procedure change_dots;
var dpos: word_index;
begin for dpos ← wlen – hyf_max downto hyf_min do
    begin if odd(hval[dpos]) then incr(dots[dpos]);
       if dots[dpos] = found_hyf then incr_wt(good_count)
       else if dots[dpos] = err_hyf then incr_wt(bad_count)
       else if dots[dpos] = is_hyf then incr_wt(miss_count);
    end;
end;

82. The following procedure outputs the word as hyphenated by the current patterns, including any word weights. Hyphens inhibited by the values of \texttt{\textbackslash leftyphenmin} and \texttt{\textbackslash rightyphenmin} are output as well.

procedure output_hyphenated_word;
var dpos: word_index;
l: trie.c pointer; { for write_letter }
begin if wt_chg then { output global word weight }
    begin write(pattmp, xdig[word_wt]); wt_chg ← false
    end;
for dpos ← 2 to wlen – 2 do
    begin write_letter(word[dpos])(pattmp); write(pattmp, xext[word[dpos]]);
       if dots[dpos] ≠ no_hyf then write(pattmp, xhyf[dots[dpos]]);
       if dotw[dpos] ≠ word_wt then write(pattmp, xdig[dotw[dpos]]);
    end;
write_letter(word[wlen − 1])(pattmp); write_in(pattmp, xext[word[wlen − 1]]);
end;
For each dot position in the current word, the `do_word` routine first checks to see if we need to consider it. It might be knocked out or a dot we don’t care about. That is, when considering hyphenating patterns, for example, we don’t need to count hyphens already found. If a relevant dot is found, we increment the count in the count trie for the corresponding pattern, inserting it first if necessary. At this point of the program range check violations may occur if these counts are incremented beyond `triec_max`; it would, however, be too expensive to prevent this.

```pascal
procedure do_word;
label continue, done;
var spos, dpos, fpos: word_index; a: triec_pointer; goodp: boolean;
begin for dpos ← wlen − dot_max downto dot_min do
  begin spos ← dpos − pat_dot; fpos ← spos + pat_len;
    (Check this dot position and goto continue if don’t care 86);
    incr(spos); a ← triec_root + word[spos];
    while spos < fpos do
      begin incr(spos); a ← triec_link(a) + word[spos];
        if so(triec_char(a)) ≠ word[spos] then
          begin { insert new count pattern }
            a ← insertc_pat(fpos); goto done;
          end;
        end;
    end;
  done: if goodp then incr_wt(triec_good(a)) else incr_wt(triec_bad(a));
  continue: end;
end;
```

The globals `good_dot` and `bad_dot` will be set to `is_hyf` and `no_hyf`, or `err_hyf` and `found_hyf`, depending on whether the current level is odd or even, respectively. The globals `dot_min`, `dot_max`, and `dot_len` are analogous to `hyf_min`, `hyf_max`, and `hyf_len` defined earlier.

```pascal
begin if procesp then
  begin dot_min ← pat_dot; dot_max ← pat_len − pat_dot;
    if dot_min < hyf_min then dot_min ← hyf_min;
    if dot_max < hyf_max then dot_max ← hyf_max;
    dot_len ← dot_min + dot_max;
    if odd(hyph_level) then
      begin good_dot ← is_hyf; bad_dot ← no_hyf;
        end
    else begin good_dot ← err_hyf; bad_dot ← found_hyf;
      end
  end;
end;
```
86. If the dot position \(dpos\) is out of bounds, knocked out, or a “don’t care”, we skip this position. Otherwise we set the flag \(goodp\) indicating whether this is a good or bad dot.

\[
\begin{align*}
\text{if } \text{no_more}[dpos] & \text{ then goto continue;}
\text{if } dots[dpos] = \text{good}_dot & \text{ then goodp } \leftarrow \text{true} \\
\text{else if } dots[dpos] = \text{bad}_dot & \text{ then goodp } \leftarrow \text{false}
\end{align*}
\]

\(\text{else goto continue;}\)

This code is used in section 83.

87. If \(hyphp\) is set to \(true\), \textit{do_dictionary} will write out a copy of the dictionary as hyphenated by the current set of patterns. If \(procesp\) is set to \(true\), \textit{do_dictionary} will collect pattern statistics for patterns with length \(pat\_len\) and hyphen position \(pat\_dot\), at level \(hyph\_level\).

\[
\begin{align*}
\text{Globals in the outer block 4} & \equiv \\
procesp, hyphp: & \text{ boolean;}
\text{pat\_dot: } & \text{ dot_type; } \{ \text{hyphen position, measured from beginning of pattern} \}
\text{hyph\_level: } & \text{ val_type; } \{ \text{hyphenation level} \}
\text{filnam: } & \text{ packed array [1..8] of char; } \{ \text{for pattmp} \}
\end{align*}
\]

88. The following procedure makes a pass through the word list, and also prints out statistics about number of hyphens found and storage used by the count trie.

\[
\begin{align*}
\text{procedure } & \textit{do_dictionary}; \\
\text{begin } & \text{good_count } \leftarrow 0; \text{ bad_count } \leftarrow 0; \text{ miss_count } \leftarrow 0; \text{ word_wt } \leftarrow 1; \text{ wt_chg } \leftarrow \text{false};
\text{reset}(dictionary); \quad \text{(Prepare to read dictionary 75)}
\text{if } & \text{procesp then} \\
& \text{begin init_count_trie;}
& \text{print}_\text{ln} ("\text{processing dictionary with pat_len} = \_\_\_\_\_\_\_\_\_\_\_\_, \text{pat_len : 1}, \_\_\_\_\_\_\_\_\_\_\_\_\_, \text{pat_dot} = \_\_\_\_\_\_\_\_\_\_\_\_, \text{pat_dot : 1});
& \text{end;}
\text{if } & \text{hyphp then} \\
& \text{begin filnam } \leftarrow "\text{pattmp.}"; \text{ filnam}[8] \leftarrow \text{xdigit[hyph\_level]; rewrite(pattmp, filnam);}
& \text{print}_\text{ln} ("\text{writing pattmp.}, \_\_\_\_\_\_\_\_\_\_\_\_, \text{xdigit[hyph\_level]};
& \text{end;}
\text{if } & \text{procesp then} \\
& \text{print}_\text{ln} (\_\_\_\_\_\_\_\_\_\_\_, \_\_\_\_\_\_\_\_\_\_\_, \text{triec_count : 1, \_\_\_\_\_\_\_\_\_\_\_, \text{triec_max : 1});}
& \text{if } \text{hyphp then close_out(pattmp);}
\text{end;}
\end{align*}
\]
89. ⟨Process words until end of file 89⟩ ≡
    while ¬eof(dictionary) do
        begin read_word;
            if wlen ≥ hyf_len then  { short words are never hyphenated }
                begin hyphenate; change_dots;
            end;
            if hyphp then
                if wlen > 2 then output_hyphenated_word; { empty words are ignored }
            if procesp then
                if wlen ≥ dot_len then do_word;
        end
This code is used in section 88.
90. Reading patterns. Before beginning a run, we can read in a file of existing patterns. This is useful for extending a previous pattern selection run to get some more levels. (Since these runs are quite time-consuming, it is convenient to choose patterns one level at a time, pausing to look at the results of the previous level, and possibly amending the dictionary.)

procedure read_patterns;
  label done, found;
  var c: text_char; d: digit; i: dot_type; t: trie_pointer;
begin xclass[" "] ← letter_class; xint[" "] ← edge_of_word; level_pattern_count ← 0; max_pat ← 0;
  reset(patterns);
  while ¬eof(patterns) do
    begin read_buf(patterns); incr(level_pattern_count);
      ⟨Get pattern and dots and goto found 92⟩;
    end;
  found: ⟨Insert pattern 93⟩;
end;

91. The global variable max_pat keeps track of the largest hyphenation value found in any pattern.

(Graphics in the outer block 4) +≡ max_pat: val_type;

92. When a new pattern has been input into buf, we extract the letters of the pattern, and insert the hyphenation values (digits) into the hval array.

(Graphics Get pattern and dots and goto found 92) ≡

  pat_len ← 0; buf_ptr ← 0; hval[0] ← 0;
  repeat incr(buf_ptr); c ← buf[buf_ptr];
    case xclass[c] of
      space_class: goto found;
      digit_class: begin d ← xint[c];
        if d ≥ max_val then bad_input("Bad hyphenation value");
        if d > max_pat then max_pat ← d;
        hval[pat_len] ← d;
      end;
      letter_class: begin incr(pat_len); hval[pat_len] ← 0; pat[pat_len] ← xint[c];
        end;
      escape_class: { record a multi-character sequence starting with c }
        begin incr(pat_len); hval[pat_len] ← 0; get_letter(pat[pat_len]);
        end;
      hyf_class, invalid_class: bad_input("Bad character");
    end;
  until buf_ptr = max_buf_len

This code is used in section 90.
93. Then we insert the pattern for each non-vanishing hyphenation value. In addition we check that edge_of_word (i.e., ’.’) occurs only as first or last character; otherwise we would have to perform a time consuming test for the end of a word in the hyphenate procedure.

⟨Insert pattern 93⟩ ≡
if pat_len > 0 then  { avoid spurious patterns }
  for i ← 0 to pat_len do
  begin if hval[i] ≠ 0 then insert_pattern(hval[i], i);
    if i > 1 then
      if i < pat_len then
        if pat[i] = edge_of_word then bad_input(’Bad_edge_of_word’);
    end
  end

This code is used in section 90.
94. The main program. This is where PATGEN actually starts. We initialize the pattern trie, get `hyph_level` and `pat_len` limits from the terminal, and generate patterns.

```
begin initialize; init_pattern_trie; read_translate; read_patterns; procesp ← true; hyphp ← false;
repeat print("hyph_start,hyph_finish;"); get_input(n1,n2);
  if (n1 ≥ 1) ∧ (n1 < max_val) ∧ (n2 ≥ 1) ∧ (n2 < max_val) then
    begin hyph_start ← n1; hyph_finish ← n2;
  end
else begin n1 ← 0; printLn("Specify 1<=hyph_start,hyph_finish<=, max_val - 1: 1, `!"'); end;
until n1 > 0;
hyph_level ← max_pat; { in case hyph_finish < hyph_start }
for i ← hyph_start to hyph_finish do
  begin hyph_level ← i; level_pattern_count ← 0;
  if hyph_level > hyph_start then printLn("`");
  else if hyph_start ≤ max_pat then printLn("Largest hyphenation value, max_pat : 1,
    in patterns should be less than hyph_start");
  repeat print("pat_start,pat_finish;"); get_input(n1,n2);
    if (n1 ≥ 1) ∧ (n1 ≤ n2) ∧ (n2 ≤ max_dot) then
      begin pat_start ← n1; pat_finish ← n2;
    end
else begin n1 ← 0; printLn("Specify 1<=pat_start<=pat_finish<=, max_dot : 1, `!"'); end;
until n1 > 0;
repeat print("good_weight,bad_weight,threshold;"); get_input(n1,n2,n3);
  if (n1 ≥ 1) ∧ (n2 ≥ 1) ∧ (n3 ≥ 1) then
    begin good_wt ← n1; bad_wt ← n2; thresh ← n3;
  end
else begin n1 ← 0; printLn("Specify good_weight,bad_weight,threshold>=1!"'); end;
until n1 > 0;
(Generate a level 96);
delete_bad_patterns;
printLn("total,of,level_pattern_count : 1,"patterns at hyph_level,hyph_level : 1");
end;
find_letters(trie_link(trie_root),1); { prepare for output }
rewrite(patout); output_patterns(trie_root,1); close_out(patout);
(Make final pass to hyphenate word list 97'};
end_of_PATGEN: end.
```

95. The patterns of a given length (at a given level) are chosen with dot positions ordered in an “organ-pipe” fashion. For example, for `pat_len = 4` we choose patterns for different dot positions in the order 2, 1, 3, 0, 4. The variable `dot1` controls this iteration in a clever manner.

(` Globals in the outer block 4 ) +≡
  n1, n2, n3: integer; { accumulators }
i: val_type; { loop index: hyphenation level }
j: dot_type; { loop index: pattern length }
k: dot_type; { loop index: hyphen position }
dot1: dot_type;
more_this_level: array [dot_type] of boolean;
96. The array more_this_level remembers which positions are permanently “knocked out”. That is, if there aren’t any possible good patterns remaining at a certain dot position, we don’t need to consider longer patterns at this level containing that position.

\[
\text{⟨ Generate a level } 96 \text{ ⟩ } \equiv
\]
\[
\text{for } k \leftarrow 0 \text{ to } \text{max_dot} \text{ do more_this_level}[k] \leftarrow \text{true};
\]
\[
\text{for } j \leftarrow \text{pat_start} \text{ to } \text{pat_finish} \text{ do}
\]
\[
\quad \text{begin pat_len } \leftarrow j; \text{ pat_dot } \leftarrow \text{pat_len} \div 2; \text{ dot1 } \leftarrow \text{pat_dot } \ast 2;
\quad \text{repeat pat_dot } \leftarrow \text{dot1 } - \text{pat_dot}; \text{ dot1 } \leftarrow \text{pat_len} \ast 2 - \text{dot1 } - 1;
\quad \text{if more_this_level[pat_dot] then}
\quad \quad \text{begin do_dictionary; collect_count_trie; more_this_level[pat_dot] } \leftarrow \text{more_to_come};
\quad \quad \text{end;}
\quad \text{until pat_dot } = \text{pat_len};
\]
\[
\text{for } k \leftarrow \text{max_dot} \text{ downto } 1 \text{ do}
\quad \text{if } \neg \text{more_this_level}[k - 1] \text{ then more_this_level}[k] \leftarrow \text{false};
\]
\text{end}

This code is used in section 94.

97. When all patterns have been found, the user has a chance to see what they do. The resulting pattmp file can be used as the new ‘dictionary’ if we want to continue pattern generation from this point.

\[
\text{⟨ Make final pass to hyphenate word list } 97 \text{ ⟩ } \equiv
\]
\[
\text{ procsyp } \leftarrow \text{false}; \text{ hyphp } \leftarrow \text{true};
\]
\[
\text{ println(”hyphenate_word_list? U”); get_inputln(buf[1]);}
\]
\[
\text{ if (buf[1] = ’Y’) } \lor \text{ (buf[1] = ’y’) then do_dictionary}
\]

This code is used in section 94.
98. **System-dependent changes.** This section should be replaced, if necessary, by changes to the program that are necessary to make PATGEN work at a particular installation. It is usually best to design your change file so that all changes to previous sections preserve the section numbering; then everybody’s version will be consistent with the printed program. More extensive changes, which introduce new sections, can be inserted here; then only the index itself will get a new section number.
99. Index.  Pointers to error messages appear here together with the section numbers where each identifier is used.

\[\text{a: 45, 48, 49, 61, 64, 83.}\]
\[\text{all_freed: 68.}\]
\[\text{any: 52.}\]
\[\text{ASCII_code: 2, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 25, 54, 59, 61.}\]
\[\text{b: 45, 48, 49, 61, 64.}\]
\[\text{bad: 4, 14, 15, 28, 54, 57, 58, 59.}\]
\[\text{Bad character: 76, 92.}\]
\[\text{Bad constants: 14.}\]
\[\text{Bad edge_of_word: 93.}\]
\[\text{Bad hyphenation data: 57.}\]
\[\text{Bad hyphenation value: 92.}\]
\[\text{Bad representation: 58, 60.}\]
\[\text{bad_count: 65, 66, 67, 81, 88.}\]
\[\text{bad_dot: 84, 85, 86.}\]
\[\text{bad Eff: 67.}\]
\[\text{bad_input: 52, 53, 57, 58, 60, 76, 92, 93.}\]
\[\text{bad_pat_count: 65, 66, 67.}\]
\[\text{bad_wt: 4, 65, 94.}\]
\[\text{banner: 1, 3.}\]
\[\text{boolean: 30, 54, 66, 68, 74, 83, 87, 95.}\]
\[\text{Breitenlohner, Peter: 2.}\]
\[\text{buf: 52, 53, 57, 58, 60, 76, 92, 97.}\]
\[\text{buf_ptr: 52, 53, 58, 60, 76, 92.}\]
\[\text{c: 19, 34, 38, 44, 48, 54, 61, 64, 68, 72, 76, 90.}\]
\[\text{change_dots: 81, 89.}\]
\[\text{char: 12, 13, 52, 87.}\]
\[\text{character set dependencies: 12, 18.}\]
\[\text{chr: 12, 16, 18, 24.}\]
\[\text{class_type: 22, 23.}\]
\[\text{close: 51.}\]
\[\text{close_in: 51, 54, 88, 90.}\]
\[\text{close_out: 51, 88, 94.}\]
\[\text{cmax: 25, 38, 48, 54, 64, 68, 72.}\]
\[\text{cmin: 25, 38, 48, 61, 64, 68, 72.}\]
\[\text{collect_count_trie: 67, 96.}\]
\[\text{continue: 8, 83, 86.}\]
\[\text{d: 39, 72, 90.}\]
\[\text{Decr: 9.}\]
\[\text{decr: 9, 39, 70, 71.}\]
\[\text{delete_bad_patterns: 36, 71, 94.}\]
\[\text{delete_patterns: 68, 70, 71.}\]
\[\text{dictionary: 3, 21, 22, 51, 52, 75, 76, 88, 89.}\]
\[\text{digit: 22, 74, 90.}\]
\[\text{digit_class: 22, 24, 57, 76, 92.}\]
\[\text{do_dictionary: 87, 88, 96, 97.}\]
\[\text{do_nothing: 9, 51, 57.}\]
\[\text{do_word: 83, 89.}\]
\[\text{done: 8, 54, 58, 60, 76, 77, 83, 90.}\]
\[\text{dot: 29, 32, 41.}\]
\[\text{dot_len: 84, 85, 89.}\]
\[\text{dot_max: 83, 84, 85.}\]
\[\text{dot_min: 83, 84, 85.}\]
\[\text{dot_type: 4, 29, 39, 40, 41, 54, 55, 61, 64, 72, 87, 90, 95.}\]
\[\text{dots: 74, 76, 81, 82, 86.}\]
\[\text{dotw: 74, 76, 81, 82.}\]
\[\text{dot1: 95, 96.}\]
\[\text{dpos: 76, 77, 80, 81, 82, 83, 86.}\]
\[\text{edge_of_word: 20, 24, 25, 54, 76, 90, 93.}\]
\[\text{end_of_PATGEN: 3, 10, 94.}\]
\[\text{eof: 54, 89, 90.}\]
\[\text{eoln: 3, 52.}\]
\[\text{err_hyf: 22, 23, 24, 57, 75, 81, 84, 85.}\]
\[\text{error: 10, 14, 53.}\]
\[\text{escape_class: 22, 59, 60, 76, 92.}\]
\[\text{exit: 8, 9, 39.}\]
\[\text{false: 34, 37, 38, 44, 47, 48, 57, 58, 67, 68, 77, 82, 86, 88, 94, 96, 97.}\]
\[\text{filnam: 87, 88.}\]
\[\text{find_letters: 61, 94.}\]
\[\text{first_fit: 35, 41, 42, 45, 59.}\]
\[\text{first_text_char: 12, 18, 24.}\]
\[\text{firste_fit: 45, 49, 50.}\]
\[\text{found: 8, 19, 35, 36, 45, 46, 76, 90, 92.}\]
\[\text{found_hyf: 22, 23, 24, 57, 75, 81, 84, 85.}\]
\[\text{fpos: 49, 77, 80, 83.}\]
\[\text{get_ASCII: 19, 58.}\]
\[\text{get_input: 3, 57, 94.}\]
\[\text{get_input_in: 3, 97.}\]
\[\text{get_letter: 60, 76, 92.}\]
\[\text{good: 4.}\]
\[\text{good_count: 65, 66, 67, 81, 88.}\]
\[\text{good_dot: 84, 85, 86.}\]
\[\text{good_pat_count: 65, 66, 67.}\]
\[\text{good_wt: 4, 65, 67, 94.}\]
\[\text{goodp: 83, 86.}\]
\[\text{goto: 10.}\]
\[\text{h: 34, 39, 68, 71, 72, 77.}\]
\[\text{hval: 73, 74, 77, 80, 81, 92, 93.}\]
\[\text{hyf_class: 22, 57, 75, 76, 92.}\]
\[\text{hyfdot: 32, 39, 73, 80.}\]
\[\text{hyflen: 78, 79, 84, 89.}\]
\[\text{hyfmax: 77, 78, 79, 81, 84, 85.}\]
\[\text{hyfmin: 78, 79, 81, 84, 85.}\]
\[\text{hyfnxt: 32, 39, 69, 73, 80.}\]
\[\text{hyftype: 22, 74, 84.}\]
\[\text{hyfval: 32, 34, 39, 69, 71, 73, 80.}\]
\[\text{hyph_finish: 4, 94.}\]
\[\text{hyph_level: 65, 80, 85, 87, 88, 94.}\]
hyphenate: 77, 89, 93.
hyphp: 87, 88, 89, 94, 97.
i: 15, 19, 41, 54, 61, 64, 90, 95.
imax: 54, 55, 56, 58, 59.
incr: 9, 19, 37, 38, 39, 41, 42, 47, 48, 49, 50, 52,
53, 56, 58, 59, 60, 62, 65, 76, 77, 81, 83, 90, 92.
Incr_Decr_end: 9.
inrt wt: 81, 83.
init_count_trie: 44, 61, 88.
init_pattern_trie: 34, 44, 94.
initialize: 3, 94.
inner loop: 22, 52, 74.
input: 3.
insert_pattern: 41, 49, 59, 65, 93.
insertc_pat: 49, 83.
integer: 4, 15, 43, 54, 66, 95.
internal_code: 20, 21, 22, 23, 25, 31, 34, 38, 40,
44, 48, 55, 59, 60, 64, 68, 72, 74.
invalid_class: 22, 24, 57, 58, 59, 75, 76, 92.
invalid_code: 18, 19.
is_hyf: 22, 24, 75, 81, 84, 85.
j: 15, 54, 61, 95.
jump_out: 10.
k: 95.
l: 61, 72, 82.
Largest hyphenation value: 94.
last_ASCII_code: 12, 13, 14, 17, 18, 19, 20, 24,
29, 34, 37, 44, 47, 54, 58, 61.
last_text_char: 12, 18, 24.
left_hyphen_min: 54, 55, 56, 57, 79.
letter_class: 22, 56, 58, 76, 90, 92.
level_pattern_count: 66, 67, 90, 94.
Liang, Franklin Mark: 2.
Line too long: 52.
loop: 9.
lower: 54, 58, 59.
max_buf_len: 27, 28, 52, 53, 58, 60, 76, 92.
max_dot: 27, 29, 57, 58, 94, 96.
max_len: 27, 28, 29, 76.
max_ops: 27, 28, 29, 34, 39, 71.
max_pat: 90, 91, 92, 94.
max_val: 27, 28, 29, 65, 69, 71, 80, 92, 94.
min_packed: 13, 14, 26, 36, 37, 38, 42, 46, 47,
48, 50, 70.
miss_count: 66, 81, 88.
more_this_level: 95, 96.
v: 39, 54, 68.
new_trie_op: 39, 41.
nil: 9.
no_hyf: 22, 75, 76, 81, 82, 84, 85.
no_more: 74, 77, 80, 94.
not_found: 8, 35, 36, 45, 46.
num_ASCII_codes: 19, 34, 37, 44, 47, 58.
n1: 57, 94, 95.
n2: 57, 94, 95.
n3: 94, 95.
odd: 81, 85.
old_op_count: 71.
old_trie_count: 71.
op: 29, 32.
op_count: 33, 34, 39, 67, 71, 90.
op_type: 29, 30, 33, 34, 39, 68, 71, 72, 77.
op_word: 29, 30.
ops: 30, 32.
ord: 16, 18.
output: 3.
output_hyphenated_word: 82, 89.
output_patterns: 72, 94.
overflow: 10, 19, 37, 39, 47, 58, 62, 76.
packed_ASCII_code: 13, 14, 20.
packed_internal_code: 20, 30.
pat: 40, 41, 42, 58, 59, 61, 62, 64, 72, 73, 92, 93.
pat_count: 43, 44, 49, 88.
pat dot: 65, 80, 83, 85, 87, 88, 96.
pat_finish: 4, 94, 96.
pat len: 40, 41, 49, 58, 59, 64, 72, 73, 80, 83, 85,
87, 88, 92, 93, 94, 95, 96.
pat start: 4, 94, 96.
PATGEN: 3.
PATGEN capacity exceeded ...: 10.
patout: 3, 21, 51, 73, 94.
patterns: 3, 21, 22, 51, 52, 90.
pattmp: 21, 51, 82, 87, 88.
print: 3, 47, 53, 57, 67, 94, 97.
print buf: 53, 58, 76.
print ln: 3, 10, 53, 54, 57, 67, 71, 88, 90, 94.
procesp: 85, 87, 88, 89, 94, 97.
q: 35, 45.
q back: 32, 45, 48, 49, 50.
q char: 32, 35, 36, 38, 41, 42, 45, 46, 48, 49, 50, 59.
q index: 29, 31, 35, 45.
q link: 32, 35, 38, 41, 42, 45, 48, 49, 50, 59.
qmax_thresh: 31, 34, 36, 71.
rang check violations: 2, 14, 83.
read: 3, 52.
read buf: 52, 54, 58, 76, 90.
read ln: 3, 52.
read patterns: 60, 90, 94.
read translate: 54, 94.
read_word: 60, 76, 89.
reset: 54, 88, 90.
return: 9.
rewrite: 88, 94.
right_hyphen_min: 54, 55, 56, 57, 79.
s: 35, 38, 41, 54, 68, 72.
si: 13, 14, 34, 35, 42, 44, 45, 50, 62.
sol: 13, 14, 38, 41, 48, 49, 59, 60, 61, 63, 64, 68, 72, 77, 83.
space_class: 22, 24, 76, 92.
spos: 49, 50, 77, 80, 83.
system_dependencies: 51, 10, 11, 12, 13, 18, 35, 52, 98.
t: 35, 38, 41, 54, 68, 71, 72, 76, 77, 90.
tab_char: 18.
text: 12.
text_char: 12, 15, 16, 19, 23, 52, 54, 76, 90.
text_file: 12, 51.
thresh: 4, 65, 67, 94.
translate: 2, 3, 6, 12, 19, 21, 51, 52, 54, 57, 58.
traverse_count_trie: 64, 67.
trie_back: 26, 32, 34, 35, 36, 37, 38, 42, 70.
trie_base_used: 26, 32, 34, 35, 36, 37, 38, 68.
trie_bmax: 33, 34, 37.
trie_c: 30, 32.
trie_char: 26, 32, 34, 35, 36, 37, 38, 41, 42, 59, 60, 61, 68, 70, 72, 77.
trie_count: 33, 34, 41, 42, 59, 60, 61, 68, 70, 72, 77.
trie_l: 30, 32.
trie_link: 26, 32, 34, 35, 36, 37, 38, 41, 42, 59, 60, 61, 68, 70, 72, 77, 94.
trie_max: 33, 34, 35, 36, 42, 67, 70, 90.
trie_outp: 26, 32, 34, 35, 38, 41, 42, 59, 60, 61, 62, 68, 69, 72, 77.
trie_pointer: 29, 30, 31, 33, 35, 38, 41, 54, 61, 68, 71, 72, 76, 77, 90.
trie_r: 30, 32.
trie_root: 26, 34, 41, 59, 60, 68, 71, 77, 94.
trie_size: 27, 28, 29, 37.
trie_taken: 30, 32.
trie_back: 32, 44, 45, 46, 47, 48, 50.
trie_bad: 32, 43, 65, 83.
trie_base_used: 32, 44, 45, 46, 47, 48.
trie_bmax: 43, 44, 47.
trie_c: 30, 32.
trie_char: 32, 44, 45, 46, 47, 48, 49, 50, 62, 63, 64, 83.
trie_good: 32, 43, 65, 83.
trie_kmax: 43, 44, 47.
trie_l: 30, 32.
(Check the "constant" values for consistency 28) Used in section 14.
(Check this dot position and goto continue if don’t care 86) Used in section 83.
(Compiler directives 11) Used in section 3.
(Deallocate this node 70) Used in section 68.
(Decide what to do with this pattern 65) Used in section 64.
(Ensure trie linked up to $b + \text{num.ASCII codes}$ 47) Used in section 46.
(Ensure trie linked up to $s + \text{num.ASCII codes}$ 37) Used in section 36.
(Generate a level 96) Used in section 94.
(Get pattern and dots and goto found 92) Used in section 90.
(Globals in the outer block 4, 16, 23, 25, 30, 31, 33, 40, 43, 51, 52, 55, 66, 74, 78, 84, 87, 91, 95) Used in section 3.
(Insert a letter into pattern trie 59) Used in section 58.
(Insert critical count transition, possibly repacking 50) Used in section 49.
(Insert critical transition, possibly repacking 42) Used in sections 41 and 59.
(Insert external representation for a letter into count trie 62) Used in section 61.
(Insert pattern 93) Used in section 90.
(Link around bad outputs 69) Used in section 68.
(Local variables for initialization 15) Used in section 3.
(Make final pass to hyphenate word list 97) Used in section 94.
(Output this pattern 73) Used in section 72.
(Prepare to read dictionary 75, 79, 85) Used in section 88.
(Process words until end of file 89) Used in section 88.
(Set initial values 14, 17, 18, 24) Used in section 3.
(Set up default character translation tables 56) Used in section 54.
(Set up representation(s) for a letter 58) Used in section 54.
(Set b to the count trie base location at which this state should be packed 46) Used in section 45.
(Set s to the trie base location at which this state should be packed 36) Used in section 35.
(Store output h in the hval and no_more arrays, and advance h 80) Used in section 77.
(Types in the outer block 12, 13, 20, 22, 29) Used in section 3.