The `VPtoVF` processor

(Version 1.5, August 1998)

1. Introduction. The VPtoVF utility program converts virtual-property-list ("VPL") files into an equivalent pair of files called a virtual font ("VF") file and a TEX font metric ("TFM") file. It also makes a thorough check of the given VPL file, so that the VF file should be acceptable to device drivers and the TFM file should be acceptable to TEX.

VPtoVF is an extended version of the program PLtoTF, which is part of the standard TEXware library. The idea of a virtual font was inspired by the work of David R. Fuchs who designed a similar set of conventions in 1984 while developing a device driver for ArborText, Inc. He wrote a somewhat similar program called PLFONT.

The *banner* string defined here should be changed whenever VPtoVF gets modified.

> **define** *banner* ≡ ´This␣is␣VPtoVF,␣Version␣1.5´   { printed when the program starts }

2. This program is written entirely in standard Pascal, except that it has to do some slightly system-dependent character code conversion on input. Furthermore, lower case letters are used in error messages; they could be converted to upper case if necessary. The input is read from *vpl_file*, and the output is written on *vf_file* and *tfm_file*; error messages and other remarks are written on the *output* file, which the user may choose to assign to the terminal if the system permits it.

The term *print* is used instead of *write* when this program writes on the *output* file, so that all such output can be easily deflected.

> **define** *print*(#) ≡ *write*(#)
> **define** *print_ln*(#) ≡ *write_ln*(#)

program *VPtoVF*(*vpl_file*, *vf_file*, *tfm_file*, *output*);
   const ⟨ Constants in the outer block 3 ⟩
   type ⟨ Types in the outer block 23 ⟩
   var ⟨ Globals in the outer block 5 ⟩
   procedure *initialize*;   { this procedure gets things started properly }
      var ⟨ Local variables for initialization 25 ⟩
      begin *print_ln*(*banner*);
      ⟨ Set initial values 6 ⟩
      end;

3. The following parameters can be changed at compile time to extend or reduce VPtoVF's capacity.

⟨ Constants in the outer block 3 ⟩ ≡
   buf_size = 60;   { length of lines displayed in error messages }
   max_header_bytes = 100;   { four times the maximum number of words allowed in the TFM file header
        block, must be 1024 or less }
   vf_size = 10000;   { maximum length of *vf* data, in bytes }
   max_stack = 100;   { maximum depth of simulated DVI stack }
   max_param_words = 30;   { the maximum number of fontdimen parameters allowed }
   max_lig_steps = 5000;   { maximum length of ligature program, must be at most $32767 - 257 = 32510$ }
   max_kerns = 500;   { the maximum number of distinct kern values }
   hash_size = 5003;
        { preferably a prime number, a bit larger than the number of character pairs in lig/kern steps }
This code is used in section 2.

4. Here are some macros for common programming idioms.

> **define** *incr*(#) ≡ # ← # + 1   { increase a variable by unity }
> **define** *decr*(#) ≡ # ← # − 1   { decrease a variable by unity }
> **define** *do_nothing* ≡   { empty statement }

5.   Property list description of font metric data.   The idea behind VPL files is that precise details about fonts, i.e., the facts that are needed by typesetting routines like TₑX, sometimes have to be supplied by hand. The nested property-list format provides a reasonably convenient way to do this.

A good deal of computation is necessary to parse and process a VPL file, so it would be inappropriate for TₑX itself to do this every time it loads a font. TₑX deals only with the compact descriptions of font metric data that appear in TFM files. Such data is so compact, however, it is almost impossible for anybody but a computer to read it.

Device drivers also need a compact way to describe mappings from TₑX's idea of a font to the actual characters a device can produce. They can do this conveniently when given a packed sequence of bytes called a VF file.

The purpose of VPtoVF is to convert from a human-oriented file of text to computer-oriented files of binary numbers. There's a companion program, VFtoVP, which goes the other way.

⟨ Globals in the outer block 5 ⟩ ≡

vpl_file: *text*;

See also sections 21, 24, 27, 29, 31, 36, 44, 46, 47, 52, 67, 75, 77, 82, 86, 89, 91, 113, 123, 138, 143, 147, 158, 161, 167, and 175.

This code is used in section 2.

6.   ⟨ Set initial values 6 ⟩ ≡

  reset(*vpl_file*);

See also sections 22, 26, 28, 30, 32, 45, 49, 68, 80, 84, and 148.

This code is used in section 2.

7.   A `VPL` file is like a `PL` file with a few extra features, so we can begin to define it by reviewing the definition of `PL` files. The material in the next few sections is copied from the program `PLtoTF`.

A `PL` file is a list of entries of the form

<p align="center">(PROPERTYNAME VALUE)</p>

where the property name is one of a finite set of names understood by this program, and the value may itself in turn be a property list. The idea is best understood by looking at an example, so let's consider a fragment of the `PL` file for a hypothetical font.

```
(FAMILY NOVA)
(FACE F MIE)
(CODINGSCHEME ASCII)
(DESIGNSIZE D 10)
(DESIGNUNITS D 18)
(COMMENT A COMMENT IS IGNORED)
(COMMENT (EXCEPT THIS ONE ISN'T))
(COMMENT (ACTUALLY IT IS, EVEN THOUGH
      IT SAYS IT ISN'T))
(FONTDIMEN
    (SLANT R -.25)
    (SPACE D 6)
    (SHRINK D 2)
    (STRETCH D 3)
    (XHEIGHT R 10.55)
    (QUAD D 18)
    )
(LIGTABLE
    (LABEL C f)
    (LIG C f O 200)
    (SKIP D 1)
    (LABEL O 200)
    (LIG C i O 201)
    (KRN O 51 R 1.5)
    (/LIG C ? C f)
    (STOP)
    )
(CHARACTER C f
    (CHARWD D 6)
    (CHARHT R 13.5)
    (CHARIC R 1.5)
    )
```

This example says that the font whose metric information is being described belongs to the hypothetical `NOVA` family; its face code is medium italic extended; and the characters appear in ASCII code positions. The design size is 10 points, and all other sizes in this `PL` file are given in units such that 18 units equals the design size. The font is slanted with a slope of $-.25$ (hence the letters actually slant backward—perhaps that is why the family name is `NOVA`). The normal space between words is 6 units (i.e., one third of the 18-unit design size), with glue that shrinks by 2 units or stretches by 3. The letters for which accents don't need to be raised or lowered are 10.55 units high, and one em equals 18 units.

The example ligature table is a bit trickier. It specifies that the letter f followed by another f is changed to code ´200, while code ´200 followed by i is changed to ´201; presumably codes ´200 and ´201 represent the ligatures 'ff' and 'ffi'. Moreover, in both cases f and ´200, if the following character is the code ´51 (which is

a right parenthesis), an additional 1.5 units of space should be inserted before the ´51 . (The 'SKIP D 1' skips over one LIG or KRN command, which in this case is the second LIG; in this way two different ligature/kern programs can come together.) Finally, if either f or ´200 is followed by a question mark, the question mark is replaced by f and the ligature program is started over. (Thus, the character pair 'f?' would actually become the ligature 'ff', and 'ff?' or 'f?f' would become 'fff'. To avoid this restart procedure, the /LIG command could be replaced by /LIG>; then 'f?' would become 'ff' and 'f?f' would become 'fff'.)

Character f itself is 6 units wide and 13.5 units tall, in this example. Its depth is zero (since CHARDP is not given), and its italic correction is 1.5 units.

8.   The example above illustrates most of the features found in PL files. Note that some property names, like FAMILY or COMMENT, take a string as their value; this string continues until the first unmatched right parenthesis. But most property names, like DESIGNSIZE and SLANT and LABEL, take a number as their value. This number can be expressed in a variety of ways, indicated by a prefixed code; D stands for decimal, H for hexadecimal, O for octal, R for real, C for character, and F for "face." Other property names, like LIG, take two numbers as their value. And still other names, like FONTDIMEN and LIGTABLE and CHARACTER, have more complicated values that involve property lists.

A property name is supposed to be used only in an appropriate property list. For example, CHARWD shouldn't occur on the outer level or within FONTDIMEN.

The individual property-and-value pairs in a property list can appear in any order. For instance, 'SHRINK' precedes 'STRETCH' in the example above, although the TFM file always puts the stretch parameter first. One could even give the information about characters like 'f' before specifying the number of units in the design size, or before specifying the ligature and kerning table. However, the LIGTABLE itself is an exception to this rule; the individual elements of the LIGTABLE property list can be reordered only to a certain extent without changing the meaning of that table.

If property-and-value pairs are omitted, a default value is used. For example, we have already noted that the default for CHARDP is zero. The default for *every* numeric value is, in fact, zero, unless otherwise stated below.

If the same property name is used more than once, VPtoVF will not notice the discrepancy; it simply uses the final value given. Once again, however, the LIGTABLE is an exception to this rule; VPtoVF will complain if there is more than one label for some character. And of course many of the entries in the LIGTABLE property list have the same property name.

9.   A VPL file also includes information about how to create each character, by typesetting characters from other fonts and/or by drawing lines, etc. Such information is the value of the 'MAP' property, which can be illustrated as follows:

```
(MAPFONT D 0 (FONTNAME Times-Roman))
(MAPFONT D 1 (FONTNAME Symbol))
(MAPFONT D 2 (FONTNAME cmr10)(FONTAT D 20))
(CHARACTER O 0 (MAP (SELECTFONT D 1)(SETCHAR C G)))
(CHARACTER O 76 (MAP (SETCHAR O 277)))
(CHARACTER D 197 (MAP
    (PUSH)(SETCHAR C A)(POP)
    (MOVEUP R 0.937)(MOVERIGHT R 1.5)(SETCHAR O 312)))
(CHARACTER O 200 (MAP (MOVEDOWN R 2.1)(SETRULE R 1 R 8)))
(CHARACTER O 201 (MAP
    (SPECIAL ps: /SaveGray currentgray def .5 setgray)
    (SELECTFONT D 2)(SETCHAR C A)
    (SPECIAL ps: SaveGray setgray)))
```

(These specifications appear in addition to the conventional PL information. The MAP attribute can be mixed in with other attributes like CHARWD or it can be given separately.)

In this example, the virtual font is composed of characters that can be fabricated from three actual fonts, 'Times-Roman', 'Symbol', and 'cmr10 at 20\u' (where \u is the unit size in this VPL file). Character ´0 is typeset as a 'G' from the symbol font. Character ´76 is typeset as character ´277 from the ordinary Times font. (If no other font is selected, font number 0 is the default. If no MAP attribute is given, the default map is a character of the same number in the default font.)

Character 197 (decimal) is more interesting: First an A is typeset (in the default font Times), and this is enclosed by PUSH and POP so that the original position is restored. Then the accent character ´312 is typeset, after moving up .937 units and right 1.5 units.

To typeset character ´200 in this virtual font, we move down 2.1 units, then typeset a rule that is 1 unit high and 8 units wide.

Finally, to typeset character ´201, we do something that requires a special ability to interpret PostScript commands; this example sets the PostScript "color" to 50% gray and typesets an 'A' from cmr10 at 20\u in that color.

In general, the MAP attribute of a virtual character can be any sequence of typesetting commands that might appear in a page of a DVI file. A single character might map into an entire page.

10.   But instead of relying on a hypothetical example, let's consider a complete grammar for VPL files, beginning with the (unchanged) grammatical rules for PL files. At the outer level, the following property names are valid in any PL file:

CHECKSUM (four-byte value). The value, which should be a nonnegative integer less than 2^{32}, is used to identify a particular version of a font; it should match the check sum value stored with the font itself. An explicit check sum of zero is used to bypass check sum testing. If no checksum is specified in the VPL file, VPtoVF will compute the checksum that METAFONT would compute from the same data.

DESIGNSIZE (numeric value, default is 10). The value, which should be a real number in the range $1.0 \leq x < 2048$, represents the default amount by which all quantities will be scaled if the font is not loaded with an 'at' specification. For example, if one says '\font\A=cmr10 at 15pt' in TEX language, the design size in the TFM file is ignored and effectively replaced by 15 points; but if one simply says '\font\A=cmr10' the stated design size is used. This quantity is always in units of printer's points.

DESIGNUNITS (numeric value, default is 1). The value should be a positive real number; it says how many units equals the design size (or the eventual 'at' size, if the font is being scaled). For example, suppose you have a font that has been digitized with 600 pixels per em, and the design size is one em; then you could say '(DESIGNUNITS R 600)' if you wanted to give all of your measurements in units of pixels.

CODINGSCHEME (string value, default is 'UNSPECIFIED'). The string should not contain parentheses, and its length must be less than 40. It identifies the correspondence between the numeric codes and font characters. (TEX ignores this information, but other software programs make use of it.)

FAMILY (string value, default is 'UNSPECIFIED'). The string should not contain parentheses, and its length must be less than 20. It identifies the name of the family to which this font belongs, e.g., 'HELVETICA'. (TEX ignores this information; but it is needed, for example, when converting DVI files to PRESS files for Xerox equipment.)

FACE (one-byte value). This number, which must lie between 0 and 255 inclusive, is a subsidiary identification of the font within its family. For example, bold italic condensed fonts might have the same family name as light roman extended fonts, differing only in their face byte. (TEX ignores this information; but it is needed, for example, when converting DVI files to PRESS files for Xerox equipment.)

SEVENBITSAFEFLAG (string value, default is 'FALSE'). The value should start with either 'T' (true) or 'F' (false). If true, character codes less than 128 cannot lead to codes of 128 or more via ligatures or charlists or extensible characters. (TEX82 ignores this flag, but older versions of TEX would only accept TFM files that were seven-bit safe.) VPtoVF computes the correct value of this flag and gives an error message only if a claimed "true" value is incorrect.

HEADER (a one-byte value followed by a four-byte value). The one-byte value should be between 18 and a maximum limit that can be raised or lowered depending on the compile-time setting of *max_header_bytes*. The four-byte value goes into the header word whose index is the one-byte value; for example, to set *header*[18] ← 1, one may write '(HEADER D 18 O 1)'. This notation is used for header information that is presently unnamed. (TEX ignores it.)

FONTDIMEN (property list value). See below for the names allowed in this property list.

LIGTABLE (property list value). See below for the rules about this special kind of property list.

BOUNDARYCHAR (one-byte value). If this character appears in a LIGTABLE command, it matches "end of word" as well as itself. If no boundary character is given and no LABEL BOUNDARYCHAR occurs within LIGTABLE, word boundaries will not affect ligatures or kerning.

CHARACTER. The value is a one-byte integer followed by a property list. The integer represents the number of a character that is present in the font; the property list of a character is defined below. The default is an empty property list.

11.   Numeric property list values can be given in various forms identified by a prefixed letter.

C denotes an ASCII character, which should be a standard visible character that is not a parenthesis. The numeric value will therefore be between ´41 and ´176 but not ´50 or ´51.

D denotes an unsigned decimal integer, which must be less than 2^{32}, i.e., at most 'D 4294967295'.

F denotes a three-letter Xerox face code; the admissible codes are MRR, MIR, BRR, BIR, LRR, LIR, MRC, MIC, BRC, BIC, LRC, LIC, MRE, MIE, BRE, BIE, LRE, and LIE, denoting the integers 0 to 17, respectively.

O denotes an unsigned octal integer, which must be less than 2^{32}, i.e., at most 'O 37777777777'.

H denotes an unsigned hexadecimal integer, which must be less than 2^{32}, i.e., at most 'H FFFFFFFF'.

R denotes a real number in decimal notation, optionally preceded by a '+' or '-' sign, and optionally including a decimal point. The absolute value must be less than 2048.

12.   The property names allowed in a FONTDIMEN property list correspond to various TeX parameters, each of which has a (real) numeric value. All of the parameters except SLANT are in design units. The admissible names are SLANT, SPACE, STRETCH, SHRINK, XHEIGHT, QUAD, EXTRASPACE, NUM1, NUM2, NUM3, DENOM1, DENOM2, SUP1, SUP2, SUP3, SUB1, SUB2, SUPDROP, SUBDROP, DELIM1, DELIM2, and AXISHEIGHT, for parameters 1 to 22. The alternate names DEFAULTRULETHICKNESS, BIGOPSPACING1, BIGOPSPACING2, BIGOPSPACING3, BIGOPSPACING4, and BIGOPSPACING5, may also be used for parameters 8 to 13.

The notation 'PARAMETER n' provides another way to specify the nth parameter; for example, '(PARAMETER D 1 R -.25)' is another way to specify that the SLANT is -0.25. The value of n must be positive and less than *max_param_words*.

13.   The elements of a CHARACTER property list can be of six different types.

CHARWD (real value) denotes the character's width in design units.

CHARHT (real value) denotes the character's height in design units.

CHARDP (real value) denotes the character's depth in design units.

CHARIC (real value) denotes the character's italic correction in design units.

NEXTLARGER (one-byte value), specifies the character that follows the present one in a "charlist." The value must be the number of a character in the font, and there must be no infinite cycles of supposedly larger and larger characters.

VARCHAR (property list value), specifies an extensible character. This option and NEXTLARGER are mutually exclusive; i.e., they cannot both be used within the same CHARACTER list.

The elements of a VARCHAR property list are either TOP, MID, BOT or REP; the values are integers, which must be zero or the number of a character in the font. A zero value for TOP, MID, or BOT means that the corresponding piece of the extensible character is absent. A nonzero value, or a REP value of zero, denotes the character code used to make up the top, middle, bottom, or replicated piece of an extensible character.

14. A `LIGTABLE` property list contains elements of four kinds, specifying a program in a simple command language that TEX uses for ligatures and kerns. If several `LIGTABLE` lists appear, they are effectively concatenated into a single list.

LABEL (one-byte value) means that the program for the stated character value starts here. The integer must be the number of a character in the font; its `CHARACTER` property list must not have a `NEXTLARGER` or `VARCHAR` field. At least one `LIG` or `KRN` step must follow.

LABEL BOUNDARYCHAR means that the program for beginning-of-word ligatures starts here.

LIG (two one-byte values). The instruction '(`LIG` c r)' means, "If the next character is c, then insert character r and possibly delete the current character and/or c; otherwise go on to the next instruction." Characters r and c must be present in the font. `LIG` may be immediately preceded or followed by a slash, and then immediately followed by `>` characters not exceeding the number of slashes. Thus there are eight possible forms:

    LIG   /LIG   /LIG>   LIG/   LIG/>   /LIG/   /LIG/>   /LIG/>>

The slashes specify retention of the left or right original character; the `>` signs specify passing over the result without further ligature processing.

KRN (a one-byte value and a real value). The instruction '(`KRN` c r)' means, "If the next character is c, then insert a blank space of width r between the current character character and c; otherwise go on to the next intruction." The value of r, which is in design units, is often negative. Character code c must exist in the font.

STOP (no value). This instruction ends a ligature/kern program. It must follow either a `LIG` or `KRN` instruction, not a `LABEL` or `STOP` or `SKIP`.

SKIP (value in the range 0 .. 127). This instruction specifies continuation of a ligature/kern program after the specified number of `LIG` or `KRN` steps has been skipped over. The number of subsequent `LIG` and `KRN` instructions must therefore exceed this specified amount.

15. In addition to all these possibilities, the property name `COMMENT` is allowed in any property list. Such comments are ignored.

16. So that is what `PL` files hold. In a `VPL` file additional properties are recognized; two of these are valid on the outermost level:

VTITLE (string value, default is empty). The value will be reproduced at the beginning of the `VF` file (and printed on the terminal by `VFtoVP` when it examines that file).

MAPFONT. The value is a nonnegative integer followed by a property list. The integer represents an identifying number for fonts used in `MAP` attributes. The property list, which identifies the font and relative size, is defined below.

And one additional "virtual property" is valid within a `CHARACTER`:

MAP. The value is a property list consisting of typesetting commands. Default is the single command **SETCHAR** c, where c is the current character number.

17.   The elements of a `MAPFONT` property list can be of the following types.

  `FONTNAME` (string value, default is `NULL`). This is the font's identifying name.

  `FONTAREA` (string value, default is empty). If the font appears in a nonstandard directory, according to local conventions, the directory name is given here. (This is system dependent, just as in `DVI` files.)

  `FONTCHECKSUM` (four-byte value, default is zero). This value, which should be a nonnegative integer less than 2^{32}, can be used to check that the font being referred to matches the intended font. If nonzero, it should equal the `CHECKSUM` parameter in that font.

  `FONTAT` (numeric value, default is the `DESIGNUNITS` of the present virtual font). This value is relative to the design units of the present virtual font, hence it will be scaled when the virtual font is magnified or reduced. It represents the value that will effectively replace the design size of the font being referred to, so that all characters will be scaled appropriately.

  `FONTDSIZE` (numeric value, default is 10). This value is absolute, in units of printer's points. It should equal the `DESIGNSIZE` parameter in the font being referred to.

If any of the string values contain parentheses, the parentheses must be balanced. Leading blanks are removed from the strings, but trailing blanks are not.

18.   Finally, the elements of a `MAP` property list are an ordered sequence of typesetting commands chosen from among the following:

  `SELECTFONT` (four-byte integer value). The value must be the number of a previously defined `MAPFONT`. This font (or more precisely, the final font that is mapped to that code number, if two `MAPFONT` properties happen to specify the same code) will be used in subsequent `SETCHAR` instructions until overridden by another `SELECTFONT`. The first-specified `MAPFONT` is implicitly selected before the first `SELECTFONT` in every character's map.

  `SETCHAR` (one-byte integer value). There must be a character of this number in the currently selected font. (`VPtoVF` doesn't check that the character is valid, but `VFtoVP` does.) That character is typeset at the current position, and the typesetter moves right by the `CHARWD` in that character's `TFM` file.

  `SETRULE` (two real values). The first value specifies height, the second specifies width, in design units. If both height and width are positive, a rule is typeset at the current position. Then the typesetter moves right, by the specified width.

  `MOVERIGHT`, `MOVELEFT`, `MOVEUP`, `MOVEDOWN` (real value). The typesetter moves its current position by the number of design units specified.

  `PUSH`. The current typesetter position is remembered, to be restored on a subsequent `POP`.

  `POP`. The current typesetter position is reset to where it was on the most recent unmatched `PUSH`. The `PUSH` and `POP` commands in any `MAP` must be properly nested like balanced parentheses.

  `SPECIAL` (string value). The subsequent characters, starting with the first nonblank and ending just before the first ')' that has no matching '(', are interpreted according to local conventions with the same system-dependent meaning as a 'special' (xxx) command in a `DVI` file.

  `SPECIALHEX` (hexadecimal string value). The subsequent nonblank characters before the next ')' must consist entirely of hexadecimal digits, and they must contain an even number of such digits. Each pair of hex digits specifies a byte, and this string of bytes is treated just as the value of a `SPECIAL`. (This convention permits arbitrary byte strings to be represented in an ordinary text file.)

19. Virtual font mapping is a recursive process, like macro expansion. Thus, a MAPFONT might specify another virtual font, whose characters are themselves mapped to other fonts. As an example of this possibility, consider the following curious file called `recurse.vpl`, which defines a virtual font that is self-contained and self-referential:

```
(VTITLE Example of recursion)
(MAPFONT D 0 (FONTNAME recurse)(FONTAT D 2))
(CHARACTER C A (CHARWD D 1)(CHARHT D 1)(MAP (SETRULE D 1 D 1)))
(CHARACTER C B (CHARWD D 2)(CHARHT D 2)(MAP (SETCHAR C A)))
(CHARACTER C C (CHARWD D 4)(CHARHT D 4)(MAP (SETCHAR C B)))
```

The design size is 10 points (the default), hence the character A in font `recurse` is a 10×10 point black square. Character B is typeset as character A in `recurse` scaled 2000, hence it is a 20×20 point black square. And character C is typeset as character B in `recurse` scaled 2000, hence its size is 40×40.

Users are responsible for making sure that infinite recursion doesn't happen.

20. So that is what VPL files hold. From these rules, you can guess (correctly) that VPtoVF operates in four main stages. First it assigns the default values to all properties; then it scans through the VPL file, changing property values as new ones are seen; then it checks the information and corrects any problems; and finally it outputs the VF and TFM files.

21. The next question is, "What are VF and TFM files?" A complete answer to that question appears in the documentation of the companion programs, VFtoVP and TFtoPL, so the details will not be repeated here. Suffice it to say that a VF or TFM file stores all of the relevant font information in a sequence of 8-bit bytes. The number of bytes is always a multiple of 4, so we could regard the files as sequences of 32-bit words; but TeX uses the byte interpretation, and so does VPtoVF. Note that the bytes are considered to be unsigned numbers.

⟨ Globals in the outer block 5 ⟩ +≡
vf_file: **packed file of** 0 . . 255;
tfm_file: **packed file of** 0 . . 255;

22. On some systems you may have to do something special to write a packed file of bytes. For example, the following code didn't work when it was first tried at Stanford, because packed files have to be opened with a special switch setting on the Pascal that was used.

⟨ Set initial values 6 ⟩ +≡
  rewrite(*vf_file*); *rewrite*(*tfm_file*);

23. Basic input routines. For the purposes of this program, a *byte* is an unsigned eight-bit quantity, and an *ASCII_code* is an integer between ´40 and ´177. Such ASCII codes correspond to one-character constants like `"A"` in WEB language.

⟨ Types in the outer block 23 ⟩ ≡
  byte = 0 . . 255; { unsigned eight-bit quantity }
  ASCII_code = ´40 . . ´177; { standard ASCII code numbers }

See also sections 66, 71, 78, and 81.

This code is used in section 2.

24. One of the things VPtoVF has to do is convert characters of strings to ASCII form, since that is the code used for the family name and the coding scheme in a TFM file. An array *xord* is used to do the conversion from *char*; the method below should work with little or no change on most Pascal systems.

  define *first_ord* = 0   { ordinal number of the smallest element of *char* }
  define *last_ord* = 127   { ordinal number of the largest element of *char* }

⟨ Globals in the outer block 5 ⟩ +≡
xord: **array** [*char*] **of** *ASCII_code*; { conversion table }

25. ⟨ Local variables for initialization 25 ⟩ ≡
k: *integer*; { all-purpose initialization index }

See also sections 48, 79, and 83.

This code is used in section 2.

26. Characters that should not appear in VPL files (except in comments) are mapped into ´177.

  define *invalid_code* = ´177   { code deserving an error message }

⟨ Set initial values 6 ⟩ +≡
  for $k \leftarrow first\_ord$ **to** $last\_ord$ **do** $xord[chr(k)] \leftarrow invalid\_code$;
  $xord[\texttt{´␣´}] \leftarrow \texttt{"␣"}$; $xord[\texttt{´!´}] \leftarrow \texttt{"!"}$; $xord[\texttt{´"´}] \leftarrow \texttt{"""}$; $xord[\texttt{´\#´}] \leftarrow \texttt{"\#"}$; $xord[\texttt{´\$´}] \leftarrow \texttt{"\$"}$;
  $xord[\texttt{´\%´}] \leftarrow \texttt{"\%"}$; $xord[\texttt{´\&´}] \leftarrow \texttt{"\&"}$; $xord[\texttt{´´´´}] \leftarrow \texttt{"´"}$; $xord[\texttt{´(´}] \leftarrow \texttt{"("}$; $xord[\texttt{´)´}] \leftarrow \texttt{")"}$;
  $xord[\texttt{´*´}] \leftarrow \texttt{"*"}$; $xord[\texttt{´+´}] \leftarrow \texttt{"+"}$; $xord[\texttt{´,´}] \leftarrow \texttt{","}$; $xord[\texttt{´-´}] \leftarrow \texttt{"-"}$; $xord[\texttt{´.´}] \leftarrow \texttt{"."}$;
  $xord[\texttt{´/´}] \leftarrow \texttt{"/"}$; $xord[\texttt{´0´}] \leftarrow \texttt{"0"}$; $xord[\texttt{´1´}] \leftarrow \texttt{"1"}$; $xord[\texttt{´2´}] \leftarrow \texttt{"2"}$; $xord[\texttt{´3´}] \leftarrow \texttt{"3"}$;
  $xord[\texttt{´4´}] \leftarrow \texttt{"4"}$; $xord[\texttt{´5´}] \leftarrow \texttt{"5"}$; $xord[\texttt{´6´}] \leftarrow \texttt{"6"}$; $xord[\texttt{´7´}] \leftarrow \texttt{"7"}$; $xord[\texttt{´8´}] \leftarrow \texttt{"8"}$;
  $xord[\texttt{´9´}] \leftarrow \texttt{"9"}$; $xord[\texttt{´:´}] \leftarrow \texttt{":"}$; $xord[\texttt{´;´}] \leftarrow \texttt{";"}$; $xord[\texttt{´<´}] \leftarrow \texttt{"<"}$; $xord[\texttt{´=´}] \leftarrow \texttt{"="}$;
  $xord[\texttt{´>´}] \leftarrow \texttt{">"}$; $xord[\texttt{´?´}] \leftarrow \texttt{"?"}$; $xord[\texttt{´@´}] \leftarrow \texttt{"@"}$; $xord[\texttt{´A´}] \leftarrow \texttt{"A"}$; $xord[\texttt{´B´}] \leftarrow \texttt{"B"}$;
  $xord[\texttt{´C´}] \leftarrow \texttt{"C"}$; $xord[\texttt{´D´}] \leftarrow \texttt{"D"}$; $xord[\texttt{´E´}] \leftarrow \texttt{"E"}$; $xord[\texttt{´F´}] \leftarrow \texttt{"F"}$; $xord[\texttt{´G´}] \leftarrow \texttt{"G"}$;
  $xord[\texttt{´H´}] \leftarrow \texttt{"H"}$; $xord[\texttt{´I´}] \leftarrow \texttt{"I"}$; $xord[\texttt{´J´}] \leftarrow \texttt{"J"}$; $xord[\texttt{´K´}] \leftarrow \texttt{"K"}$; $xord[\texttt{´L´}] \leftarrow \texttt{"L"}$;
  $xord[\texttt{´M´}] \leftarrow \texttt{"M"}$; $xord[\texttt{´N´}] \leftarrow \texttt{"N"}$; $xord[\texttt{´O´}] \leftarrow \texttt{"O"}$; $xord[\texttt{´P´}] \leftarrow \texttt{"P"}$; $xord[\texttt{´Q´}] \leftarrow \texttt{"Q"}$;
  $xord[\texttt{´R´}] \leftarrow \texttt{"R"}$; $xord[\texttt{´S´}] \leftarrow \texttt{"S"}$; $xord[\texttt{´T´}] \leftarrow \texttt{"T"}$; $xord[\texttt{´U´}] \leftarrow \texttt{"U"}$; $xord[\texttt{´V´}] \leftarrow \texttt{"V"}$;
  $xord[\texttt{´W´}] \leftarrow \texttt{"W"}$; $xord[\texttt{´X´}] \leftarrow \texttt{"X"}$; $xord[\texttt{´Y´}] \leftarrow \texttt{"Y"}$; $xord[\texttt{´Z´}] \leftarrow \texttt{"Z"}$; $xord[\texttt{´[´}] \leftarrow \texttt{"["}$;
  $xord[\texttt{´\textbackslash´}] \leftarrow \texttt{"\textbackslash"}$; $xord[\texttt{´]´}] \leftarrow \texttt{"]"}$; $xord[\texttt{´^´}] \leftarrow \texttt{"^"}$; $xord[\texttt{´\_´}] \leftarrow \texttt{"\_"}$; $xord[\texttt{´`´}] \leftarrow \texttt{"`"}$;
  $xord[\texttt{´a´}] \leftarrow \texttt{"a"}$; $xord[\texttt{´b´}] \leftarrow \texttt{"b"}$; $xord[\texttt{´c´}] \leftarrow \texttt{"c"}$; $xord[\texttt{´d´}] \leftarrow \texttt{"d"}$; $xord[\texttt{´e´}] \leftarrow \texttt{"e"}$;
  $xord[\texttt{´f´}] \leftarrow \texttt{"f"}$; $xord[\texttt{´g´}] \leftarrow \texttt{"g"}$; $xord[\texttt{´h´}] \leftarrow \texttt{"h"}$; $xord[\texttt{´i´}] \leftarrow \texttt{"i"}$; $xord[\texttt{´j´}] \leftarrow \texttt{"j"}$;
  $xord[\texttt{´k´}] \leftarrow \texttt{"k"}$; $xord[\texttt{´l´}] \leftarrow \texttt{"l"}$; $xord[\texttt{´m´}] \leftarrow \texttt{"m"}$; $xord[\texttt{´n´}] \leftarrow \texttt{"n"}$; $xord[\texttt{´o´}] \leftarrow \texttt{"o"}$;
  $xord[\texttt{´p´}] \leftarrow \texttt{"p"}$; $xord[\texttt{´q´}] \leftarrow \texttt{"q"}$; $xord[\texttt{´r´}] \leftarrow \texttt{"r"}$; $xord[\texttt{´s´}] \leftarrow \texttt{"s"}$; $xord[\texttt{´t´}] \leftarrow \texttt{"t"}$;
  $xord[\texttt{´u´}] \leftarrow \texttt{"u"}$; $xord[\texttt{´v´}] \leftarrow \texttt{"v"}$; $xord[\texttt{´w´}] \leftarrow \texttt{"w"}$; $xord[\texttt{´x´}] \leftarrow \texttt{"x"}$; $xord[\texttt{´y´}] \leftarrow \texttt{"y"}$;
  $xord[\texttt{´z´}] \leftarrow \texttt{"z"}$; $xord[\texttt{´\{´}] \leftarrow \texttt{"\{"}$; $xord[\texttt{´|´}] \leftarrow \texttt{"|"}$; $xord[\texttt{´\}´}] \leftarrow \texttt{"\}"}$; $xord[\texttt{´~´}] \leftarrow \texttt{"~"}$;

27.   In order to help catch errors of badly nested parentheses, VPtoVF assumes that the user will begin each line with a number of blank spaces equal to some constant times the number of open parentheses at the beginning of that line. However, the program doesn't know in advance what the constant is, nor does it want to print an error message on every line for a user who has followed no consistent pattern of indentation.

   Therefore the following strategy is adopted: If the user has been consistent with indentation for ten or more lines, an indentation error will be reported. The constant of indentation is reset on every line that should have nonzero indentation.

⟨ Globals in the outer block 5 ⟩ +≡
line: *integer*;   { the number of the current line }
good_indent: *integer*;   { the number of lines since the last bad indentation }
indent: *integer*;   { the number of spaces per open parenthesis, zero if unknown }
level: *integer*;   { the current number of open parentheses }

28.   ⟨ Set initial values 6 ⟩ +≡
   line ← 0; *good_indent* ← 0; *indent* ← 0; *level* ← 0;

29.   The input need not really be broken into lines of any maximum length, and we could read it character by character without any buffering. But we shall place it into a small buffer so that offending lines can be displayed in error messages.

⟨ Globals in the outer block 5 ⟩ +≡
left_ln, *right_ln*: *boolean*;   { are the left and right ends of the buffer at end-of-line marks? }
limit: 0 . . *buf_size*;   { position of the last character present in the buffer }
loc: 0 . . *buf_size*;   { position of the last character read in the buffer }
buffer: **array** [1 . . *buf_size*] **of** *char*;
input_has_ended: *boolean*;   { there is no more input to read }

30.   ⟨ Set initial values 6 ⟩ +≡
   limit ← 0; *loc* ← 0; *left_ln* ← *true*; *right_ln* ← *true*; *input_has_ended* ← *false*;

31.   Just before each CHARACTER property list is evaluated, the character code is printed in octal notation. Up to eight such codes appear on a line; so we have a variable to keep track of how many are currently there.

⟨ Globals in the outer block 5 ⟩ +≡
chars_on_line: 0 . . 8;   { the number of characters printed on the current line }

32.   ⟨ Set initial values 6 ⟩ +≡
   chars_on_line ← 0;

33. The following routine prints an error message and an indication of where the error was detected. The error message should not include any final punctuation, since this procedure supplies its own.

> **define** *err_print*(#) ≡
> > **begin if** *chars_on_line* > 0 **then** *print_ln*(´␣´);
> > *print*(#); *show_error_context*;
> > **end**

procedure *show_error_context*;   { prints the current scanner location }
>   **var** *k*: 0 . . *buf_size*;   { an index into *buffer* }
>   **begin** *print_ln*(´␣(line␣´, *line* : 1, ´).´);
>   **if** ¬*left_ln* **then** *print*(´...´);
>   **for** *k* ← 1 **to** *loc* **do** *print*(*buffer*[*k*]);   { print the characters already scanned }
>   *print_ln*(´␣´);
>   **if** ¬*left_ln* **then** *print*(´␣␣␣´);
>   **for** *k* ← 1 **to** *loc* **do** *print*(´␣´);   { space out the second line }
>   **for** *k* ← *loc* + 1 **to** *limit* **do** *print*(*buffer*[*k*]);   { print the characters yet unseen }
>   **if** *right_ln* **then** *print_ln*(´␣´) **else** *print_ln*(´...´);
>   *chars_on_line* ← 0;
>   **end**;

34. Here is a procedure that does the right thing when we are done reading the present contents of the buffer. It keeps *buffer*[*buf_size*] empty, in order to avoid range errors on certain Pascal compilers.

An infinite sequence of right parentheses is placed at the end of the file, so that the program is sure to get out of whatever level of nesting it is in.

On some systems it is desirable to modify this code so that tab marks in the buffer are replaced by blank spaces. (Simply setting *xord*[*chr*(´11´)] ← "␣" would not work; for example, two-line error messages would not come out properly aligned.)

procedure *fill_buffer*;
>   **begin** *left_ln* ← *right_ln*; *limit* ← 0; *loc* ← 0;
>   **if** *left_ln* **then**
>   > **begin if** *line* > 0 **then** *read_ln*(*vpl_file*);
>   > *incr*(*line*);
>   > **end**;
>   **if** *eof*(*vpl_file*) **then**
>   > **begin** *limit* ← 1; *buffer*[1] ← ´)´; *right_ln* ← *false*; *input_has_ended* ← *true*;
>   > **end**
>   **else begin while** (*limit* < *buf_size* − 1) ∧ (¬*eoln*(*vpl_file*)) **do**
>   > > **begin** *incr*(*limit*); *read*(*vpl_file*, *buffer*[*limit*]);
>   > > **end**;
>   > *buffer*[*limit* + 1] ← ´␣´; *right_ln* ← *eoln*(*vpl_file*);
>   > **if** *left_ln* **then** ⟨ Set *loc* to the number of leading blanks in the buffer, and check the indentation 35 ⟩;
>   > **end**;
>   **end**;

35.   The interesting part about *fill_buffer* is the part that learns what indentation conventions the user is following, if any.

> **define** *bad_indent*(#) ≡
>> **begin if** *good_indent* ≥ 10 **then** *err_print*(#);
>> *good_indent* ← 0; *indent* ← 0;
>> **end**

⟨ Set *loc* to the number of leading blanks in the buffer, and check the indentation 35 ⟩ ≡
> **begin while** (*loc* < *limit*) ∧ (*buffer*[*loc* + 1] = ´␣´) **do** *incr*(*loc*);
> **if** *loc* < *limit* **then**
>> **begin if** *level* = 0 **then**
>>> **if** *loc* = 0 **then** *incr*(*good_indent*)
>>> **else** *bad_indent*(´Warning:␣Indented␣line␣occurred␣at␣level␣zero´)
>>
>> **else if** *indent* = 0 **then**
>>> **if** *loc* **mod** *level* = 0 **then**
>>>> **begin** *indent* ← *loc* **div** *level*; *good_indent* ← 1;
>>>> **end**
>>>
>>> **else** *good_indent* ← 0
>>
>> **else if** *indent* * *level* = *loc* **then** *incr*(*good_indent*)
>>> **else** *bad_indent*(´Warning:␣Inconsistent␣indentation;␣´,
>>>> ´you␣are␣at␣parenthesis␣level␣´, *level* : 1);
>>
>> **end**;
>
> **end**

This code is used in section 34.

36. Basic scanning routines.   The global variable *cur_char* holds the ASCII code corresponding to the character most recently read from the input buffer, or to a character that has been substituted for the real one.

⟨ Globals in the outer block 5 ⟩ +≡
cur_char: *ASCII_code*;   { we have just read this }

37.   Here is a procedure that sets *cur_char* to an ASCII code for the next character of input, if that character is a letter or digit or slash or >. Otherwise it sets *cur_char* ← "␣", and the input system will be poised to reread the character that was rejected, whether or not it was a space. Lower case letters are converted to upper case.

procedure *get_keyword_char*;
  begin while (*loc* = *limit*) ∧ (¬*right_ln*) **do** *fill_buffer*;
  if *loc* = *limit* **then** *cur_char* ← "␣"   { end-of-line counts as a delimiter }
  else begin *cur_char* ← *xord*[*buffer*[*loc* + 1]];
    if *cur_char* ≥ "a" **then** *cur_char* ← *cur_char* − ´40;
    if ((*cur_char* ≥ "0") ∧ (*cur_char* ≤ "9")) **then** *incr*(*loc*)
    else if ((*cur_char* ≥ "A") ∧ (*cur_char* ≤ "Z")) **then** *incr*(*loc*)
      else if *cur_char* = "/" **then** *incr*(*loc*)
        else if *cur_char* = ">" **then** *incr*(*loc*)
          else *cur_char* ← "␣";
    end;
  end;

38.   The following procedure sets *cur_char* to the next character code, and converts lower case to upper case. If the character is a left or right parenthesis, it will not be "digested"; the character will be read again and again, until the calling routine does something like '*incr*(*loc*)' to get past it. Such special treatment of parentheses insures that the structural information they contain won't be lost in the midst of other error recovery operations.

  define *backup* ≡
        begin if (*cur_char* > ")") ∨ (*cur_char* < "(") **then** *decr*(*loc*);
        end   { undoes the effect of *get_next* }

procedure *get_next*;   { sets *cur_char* to next, balks at parentheses }
  begin while *loc* = *limit* **do** *fill_buffer*;
  incr(*loc*); *cur_char* ← *xord*[*buffer*[*loc*]];
  if *cur_char* ≥ "a" **then**
    if *cur_char* ≤ "z" **then** *cur_char* ← *cur_char* − ´40   { uppercasify }
    else begin if *cur_char* = *invalid_code* **then**
      begin *err_print*(´Illegal␣character␣in␣the␣file´); *cur_char* ← "?";
      end;
      end
  else if (*cur_char* ≤ ")") ∧ (*cur_char* ≥ "(") **then** *decr*(*loc*);
  end;

39.   Here's a procedure that scans a hexadecimal digit or a right parenthesis.

function get_hex: $byte$;
  var a: $integer$;   { partial result }
  begin repeat get_next;
  until $cur\_char \neq$ "␣";
  $a \leftarrow cur\_char -$ ")";
  if $a > 0$ **then**
    begin $a \leftarrow cur\_char -$ "0";
    if $cur\_char >$ "9" **then**
      if $cur\_char <$ "A" **then** $a \leftarrow -1$
      else $a \leftarrow cur\_char -$ "A" $+ 10$;
    end;
  if $(a < 0) \vee (a > 15)$ **then**
    begin $err\_print($´Illegal␣hexadecimal␣digit´$)$; $get\_hex \leftarrow 0$;
    end
  else $get\_hex \leftarrow a$;
  end;

40.   The next procedure is used to ignore the text of a comment, or to pass over erroneous material. As such, it has the privilege of passing parentheses. It stops after the first right parenthesis that drops the level below the level in force when the procedure was called.

procedure $skip\_to\_end\_of\_item$;
  var l: $integer$;   { initial value of $level$ }
  begin $l \leftarrow level$;
  while $level \geq l$ **do**
    begin while $loc = limit$ **do** $fill\_buffer$;
    $incr(loc)$;
    if $buffer[loc] =$ ´)´ **then** $decr(level)$
    else if $buffer[loc] =$ ´(´ **then** $incr(level)$;
    end;
  if $input\_has\_ended$ **then** $err\_print($´File␣ended␣unexpectedly:␣No␣closing␣")"´$)$;
  $cur\_char \leftarrow$ "␣";   { now the right parenthesis has been read and digested }
  end;

41. A similar procedure copies the bytes remaining in an item. The copied bytes go into an array vf that we'll declare later. Leading blanks are ignored.

define $vf\_store(\#) \equiv$
   begin $vf[vf\_ptr] \gets \#;$
   if $vf\_ptr = vf\_size$ **then** $err\_print(´I´´m\_out\_of\_memory{-}{-}{-}increase\_my\_vfsize!´)$
   else $incr(vf\_ptr);$
   end

procedure $copy\_to\_end\_of\_item;$
 label 30;
 var l: $integer;$ { initial value of $level$ }
  $nonblank\_found$: $boolean;$ { have we seen a nonblank character yet? }
 begin $l \gets level;$ $nonblank\_found \gets false;$
 while $true$ **do**
  begin while $loc = limit$ **do** $fill\_buffer;$
  if $buffer[loc + 1] = ´)´$ **then**
   if $level = l$ **then goto** 30 **else** $decr(level);$
  $incr(loc);$
  if $buffer[loc] = ´(´$ **then** $incr(level);$
  if $buffer[loc] \neq ´\_´$ **then** $nonblank\_found \gets true;$
  if $nonblank\_found$ **then**
   if $xord[buffer[loc]] = invalid\_code$ **then**
    begin $err\_print(´Illegal\_character\_in\_the\_file´);$ $vf\_store("?");$
    end
   else $vf\_store(xord[buffer[loc]]);$
  end;
30: **end**;

42. Sometimes we merely want to skip past characters in the input until we reach a left or a right parenthesis. For example, we do this whenever we have finished scanning a property value and we hope that a right parenthesis is next (except for possible blank spaces).

define $skip\_to\_paren \equiv$
   repeat get_next **until** $(cur\_char = "(") \vee (cur\_char = ")")$
define $skip\_error(\#) \equiv$
   begin $err\_print(\#);$ $skip\_to\_paren;$
   end { this gets to the right parenthesis if something goes wrong }
define $flush\_error(\#) \equiv$
   begin $err\_print(\#);$ $skip\_to\_end\_of\_item;$
   end { this gets past the right parenthesis if something goes wrong }

43. After a property value has been scanned, we want to move just past the right parenthesis that should come next in the input (except for possible blank spaces).

procedure $finish\_the\_property;$ { do this when the value has been scanned }
 begin while $cur\_char = "\_"$ **do** $get\_next;$
 if $cur\_char \neq ")"$ **then** $err\_print(´Junk\_after\_property\_value\_will\_be\_ignored´);$
 $skip\_to\_end\_of\_item;$
 end;

44.   Scanning property names.   We have to figure out the meaning of names that appear in the VPL file, by looking them up in a dictionary of known keywords. Keyword number n appears in locations $start[n]$ through $start[n+1] - 1$ of an array called *dictionary*.

define $max\_name\_index = 100$ { upper bound on the number of keywords }
define $max\_letters = 666$ { upper bound on the total length of all keywords }

⟨ Globals in the outer block 5 ⟩ +≡
$start$: **array** $[1 \mathbin{..} max\_name\_index]$ **of** $0 \mathbin{..} max\_letters$;
$dictionary$: **array** $[0 \mathbin{..} max\_letters]$ **of** $ASCII\_code$;
$start\_ptr$: $0 \mathbin{..} max\_name\_index$;   { the first available place in *start* }
$dict\_ptr$: $0 \mathbin{..} max\_letters$;   { the first available place in *dictionary* }

45.   ⟨ Set initial values 6 ⟩ +≡
  $start\_ptr \leftarrow 1$; $start[1] \leftarrow 0$; $dict\_ptr \leftarrow 0$;

46.   When we are looking for a name, we put it into the *cur_name* array. When we have found it, the corresponding *start* index will go into the global variable *name_ptr*.

define $longest\_name = 20$ { length of DEFAULTRULETHICKNESS }

⟨ Globals in the outer block 5 ⟩ +≡
cur_name: **array** $[1 \mathbin{..} longest\_name]$ **of** $ASCII\_code$;   { a name to look up }
$name\_length$: $0 \mathbin{..} longest\_name$;   { its length }
$name\_ptr$: $0 \mathbin{..} max\_name\_index$;   { its ordinal number in the dictionary }

47.   A conventional hash table with linear probing (cf. Algorithm 6.4L in *The Art of Computer Programming*) is used for the dictionary operations. If $nhash[h] = 0$, the table position is empty, otherwise $nhash[h]$ points into the *start* array.

define $hash\_prime = 141$ { size of the hash table }

⟨ Globals in the outer block 5 ⟩ +≡
$nhash$: **array** $[0 \mathbin{..} hash\_prime - 1]$ **of** $0 \mathbin{..} max\_name\_index$;
cur_hash: $0 \mathbin{..} hash\_prime - 1$;   { current position in the hash table }

48.   ⟨ Local variables for initialization 25 ⟩ +≡
h: $0 \mathbin{..} hash\_prime - 1$;   { runs through the hash table }

49.   ⟨ Set initial values 6 ⟩ +≡
  for $h \leftarrow 0$ **to** $hash\_prime - 1$ **do** $nhash[h] \leftarrow 0$;

50.   Since there is no chance of the hash table overflowing, the procedure is very simple. After *lookup* has done its work, *cur_hash* will point to the place where the given name was found, or where it should be inserted.

```
procedure lookup;  { finds cur_name in the dictionary }
   var k: 0 .. longest_name;  { index into cur_name }
      j: 0 .. max_letters;  { index into dictionary }
      not_found: boolean;  { clumsy thing necessary to avoid goto statement }
   begin ⟨ Compute the hash code, cur_hash, for cur_name  51 ⟩;
   not_found ← true;
   while not_found do
      begin if cur_hash = 0 then  cur_hash ← hash_prime − 1 else decr(cur_hash);
      if nhash[cur_hash] = 0 then  not_found ← false
      else begin j ← start[nhash[cur_hash]];
         if start[nhash[cur_hash] + 1] = j + name_length then
            begin not_found ← false;
            for k ← 1 to name_length do
               if dictionary[j + k − 1] ≠ cur_name[k] then  not_found ← true;
            end;
         end;
      end;
   name_ptr ← nhash[cur_hash];
   end;
```

51.   ⟨ Compute the hash code, *cur_hash*, for *cur_name* 51 ⟩ ≡
   $cur\_hash \leftarrow cur\_name[1]$;
   for $k \leftarrow 2$ **to** *name_length* **do** $cur\_hash \leftarrow (cur\_hash + cur\_hash + cur\_name[k]) \bmod hash\_prime$

This code is used in section 50.

52. The "meaning" of the keyword that begins at $start[k]$ in the dictionary is kept in $equiv[k]$. The numeric $equiv$ codes are given symbolic meanings by the following definitions.

define $comment\_code = 0$
define $check\_sum\_code = 1$
define $design\_size\_code = 2$
define $design\_units\_code = 3$
define $coding\_scheme\_code = 4$
define $family\_code = 5$
define $face\_code = 6$
define $seven\_bit\_safe\_flag\_code = 7$
define $header\_code = 8$
define $font\_dimen\_code = 9$
define $lig\_table\_code = 10$
define $boundary\_char\_code = 11$
define $virtual\_title\_code = 12$
define $map\_font\_code = 13$
define $character\_code = 14$
define $font\_name\_code = 20$
define $font\_area\_code = 21$
define $font\_checksum\_code = 22$
define $font\_at\_code = 23$
define $font\_dsize\_code = 24$
define $parameter\_code = 30$
define $char\_info\_code = 60$
define $width = 1$
define $height = 2$
define $depth = 3$
define $italic = 4$
define $char\_wd\_code = char\_info\_code + width$
define $char\_ht\_code = char\_info\_code + height$
define $char\_dp\_code = char\_info\_code + depth$
define $char\_ic\_code = char\_info\_code + italic$
define $next\_larger\_code = 65$
define $map\_code = 66$
define $var\_char\_code = 67$
define $select\_font\_code = 80$
define $set\_char\_code = 81$
define $set\_rule\_code = 82$
define $move\_right\_code = 83$
define $move\_down\_code = 85$
define $push\_code = 87$
define $pop\_code = 88$
define $special\_code = 89$
define $special\_hex\_code = 90$
define $label\_code = 100$
define $stop\_code = 101$
define $skip\_code = 102$
define $krn\_code = 103$
define $lig\_code = 104$

⟨ Globals in the outer block 5 ⟩ +≡
$equiv$: **array** $[0 .. max\_name\_index]$ **of** $byte$;
cur_code: $byte$;   { equivalent most recently found in $equiv$ }

53. We have to get the keywords into the hash table and into the dictionary in the first place (sigh). The procedure that does this has the desired *equiv* code as a parameter. In order to facilitate WEB macro writing for the initialization, the keyword being initialized is placed into the last positions of *cur_name*, instead of the first positions.

procedure *enter_name*(*v* : *byte*);   { *cur_name* goes into the dictionary }
   var *k*: 0 .. *longest_name*;
   begin for *k* ← 1 **to** *name_length* **do** *cur_name*[*k*] ← *cur_name*[*k* + *longest_name* − *name_length*];
       { now the name has been shifted into the correct position }
   lookup;   { this sets *cur_hash* to the proper insertion place }
   nhash[*cur_hash*] ← *start_ptr*; *equiv*[*start_ptr*] ← *v*;
   for *k* ← 1 **to** *name_length* **do**
     begin *dictionary*[*dict_ptr*] ← *cur_name*[*k*]; *incr*(*dict_ptr*);
     end;
   incr(*start_ptr*); *start*[*start_ptr*] ← *dict_ptr*;
   end;

54.   Here are the macros to load a name of up to 20 letters into the dictionary. For example, the macro
load5 is used for five-letter keywords.

    define $tail(\#) \equiv enter\_name(\#)$
    define $t20(\#) \equiv cur\_name[20] \leftarrow \#;\ tail$
    define $t19(\#) \equiv cur\_name[19] \leftarrow \#;\ t20$
    define $t18(\#) \equiv cur\_name[18] \leftarrow \#;\ t19$
    define $t17(\#) \equiv cur\_name[17] \leftarrow \#;\ t18$
    define $t16(\#) \equiv cur\_name[16] \leftarrow \#;\ t17$
    define $t15(\#) \equiv cur\_name[15] \leftarrow \#;\ t16$
    define $t14(\#) \equiv cur\_name[14] \leftarrow \#;\ t15$
    define $t13(\#) \equiv cur\_name[13] \leftarrow \#;\ t14$
    define $t12(\#) \equiv cur\_name[12] \leftarrow \#;\ t13$
    define $t11(\#) \equiv cur\_name[11] \leftarrow \#;\ t12$
    define $t10(\#) \equiv cur\_name[10] \leftarrow \#;\ t11$
    define $t9(\#) \equiv cur\_name[9] \leftarrow \#;\ t10$
    define $t8(\#) \equiv cur\_name[8] \leftarrow \#;\ t9$
    define $t7(\#) \equiv cur\_name[7] \leftarrow \#;\ t8$
    define $t6(\#) \equiv cur\_name[6] \leftarrow \#;\ t7$
    define $t5(\#) \equiv cur\_name[5] \leftarrow \#;\ t6$
    define $t4(\#) \equiv cur\_name[4] \leftarrow \#;\ t5$
    define $t3(\#) \equiv cur\_name[3] \leftarrow \#;\ t4$
    define $t2(\#) \equiv cur\_name[2] \leftarrow \#;\ t3$
    define $t1(\#) \equiv cur\_name[1] \leftarrow \#;\ t2$
    define $load3 \equiv name\_length \leftarrow 3;\ t18$
    define $load4 \equiv name\_length \leftarrow 4;\ t17$
    define $load5 \equiv name\_length \leftarrow 5;\ t16$
    define $load6 \equiv name\_length \leftarrow 6;\ t15$
    define $load7 \equiv name\_length \leftarrow 7;\ t14$
    define $load8 \equiv name\_length \leftarrow 8;\ t13$
    define $load9 \equiv name\_length \leftarrow 9;\ t12$
    define $load10 \equiv name\_length \leftarrow 10;\ t11$
    define $load11 \equiv name\_length \leftarrow 11;\ t10$
    define $load12 \equiv name\_length \leftarrow 12;\ t9$
    define $load13 \equiv name\_length \leftarrow 13;\ t8$
    define $load14 \equiv name\_length \leftarrow 14;\ t7$
    define $load15 \equiv name\_length \leftarrow 15;\ t6$
    define $load16 \equiv name\_length \leftarrow 16;\ t5$
    define $load17 \equiv name\_length \leftarrow 17;\ t4$
    define $load18 \equiv name\_length \leftarrow 18;\ t3$
    define $load19 \equiv name\_length \leftarrow 19;\ t2$
    define $load20 \equiv name\_length \leftarrow 20;\ t1$

55. (Thank goodness for keyboard macros in the text editor used to create this `WEB` file.)

⟨ Enter all the `PL` names and their equivalents, except the parameter names 55 ⟩ ≡

  $equiv[0] \leftarrow comment\_code$;   { this is used after unknown keywords }

  $load8$ ("C")("H")("E")("C")("K")("S")("U")("M")($check\_sum\_code$);

  $load10$ ("D")("E")("S")("I")("G")("N")("S")("I")("Z")("E")($design\_size\_code$);

  $load11$ ("D")("E")("S")("I")("G")("N")("U")("N")("I")("T")("S")($design\_units\_code$);

  $load12$ ("C")("O")("D")("I")("N")("G")("S")("C")("H")("E")("M")("E")($coding\_scheme\_code$);

  $load6$ ("F")("A")("M")("I")("L")("Y")($family\_code$);

  $load4$ ("F")("A")("C")("E")($face\_code$);

  $load16$ ("S")("E")("V")("E")("N")("B")("I")("T")

      ("S")("A")("F")("E")("F")("L")("A")("G")($seven\_bit\_safe\_flag\_code$);

  $load6$ ("H")("E")("A")("D")("E")("R")($header\_code$);

  $load9$ ("F")("O")("N")("T")("D")("I")("M")("E")("N")($font\_dimen\_code$);

  $load8$ ("L")("I")("G")("T")("A")("B")("L")("E")(lig_table_code);

  $load12$ ("B")("O")("U")("N")("D")("A")("R")("Y")("C")("H")("A")("R")($boundary\_char\_code$);

  $load9$ ("C")("H")("A")("R")("A")("C")("T")("E")("R")($character\_code$);

  $load9$ ("P")("A")("R")("A")("M")("E")("T")("E")("R")($parameter\_code$);

  $load6$ ("C")("H")("A")("R")("W")("D")($char\_wd\_code$);

  $load6$ ("C")("H")("A")("R")("H")("T")($char\_ht\_code$);

  $load6$ ("C")("H")("A")("R")("D")("P")($char\_dp\_code$);

  $load6$ ("C")("H")("A")("R")("I")("C")($char\_ic\_code$);

  $load10$ ("N")("E")("X")("T")("L")("A")("R")("G")("E")("R")($next\_larger\_code$);

  $load7$ ("V")("A")("R")("C")("H")("A")("R")(var_char_code);

  $load3$ ("T")("O")("P")($var\_char\_code + 1$);

  $load3$ ("M")("I")("D")($var\_char\_code + 2$);

  $load3$ ("B")("O")("T")($var\_char\_code + 3$);

  $load3$ ("R")("E")("P")($var\_char\_code + 4$);

  $load3$ ("E")("X")("T")($var\_char\_code + 4$);   { compatibility with older `PL` format }

  $load7$ ("C")("O")("M")("M")("E")("N")("T")($comment\_code$);

  $load5$ ("L")("A")("B")("E")("L")($label\_code$);

  $load4$ ("S")("T")("O")("P")($stop\_code$);

  $load4$ ("S")("K")("I")("P")($skip\_code$);

  $load3$ ("K")("R")("N")(krn_code);

  $load3$ ("L")("I")("G")(lig_code);

  $load4$ ("/")("L")("I")("G")($lig\_code + 2$);

  $load5$ ("/")("L")("I")("G")(">")($lig\_code + 6$);

  $load4$ ("L")("I")("G")("/")($lig\_code + 1$);

  $load5$ ("L")("I")("G")("/")(">")($lig\_code + 5$);

  $load5$ ("/")("L")("I")("G")("/")($lig\_code + 3$);

  $load6$ ("/")("L")("I")("G")("/")(">")($lig\_code + 7$);

  $load7$ ("/")("L")("I")("G")("/")(">")(">")($lig\_code + 11$);

This code is used in section 180.

56.   VPL files may contain the following in addition to the PL names.

⟨ Enter all the VPL names 56 ⟩ ≡
  $load6$ ("V")("T")("I")("T")("L")("E")($virtual\_title\_code$);
  $load7$ ("M")("A")("P")("F")("O")("N")("T")(map_font_code);
  $load3$ ("M")("A")("P")(map_code);
  $load8$ ("F")("O")("N")("T")("N")("A")("M")("E")($font\_name\_code$);
  $load8$ ("F")("O")("N")("T")("A")("R")("E")("A")($font\_area\_code$);
  $load12$ ("F")("O")("N")("T")("C")("H")("E")("C")("K")("S")("U")("M")($font\_checksum\_code$);
  $load6$ ("F")("O")("N")("T")("A")("T")($font\_at\_code$);
  $load9$ ("F")("O")("N")("T")("D")("S")("I")("Z")("E")($font\_dsize\_code$);
  $load10$ ("S")("E")("L")("E")("C")("T")("F")("O")("N")("T")($select\_font\_code$);
  $load7$ ("S")("E")("T")("C")("H")("A")("R")(set_char_code);
  $load7$ ("S")("E")("T")("R")("U")("L")("E")(set_rule_code);
  $load9$ ("M")("O")("V")("E")("R")("I")("G")("H")("T")($move\_right\_code$);
  $load8$ ("M")("O")("V")("E")("L")("E")("F")("T")($move\_right\_code + 1$);
  $load8$ ("M")("O")("V")("E")("D")("O")("W")("N")($move\_down\_code$);
  $load6$ ("M")("O")("V")("E")("U")("P")($move\_down\_code + 1$);
  $load4$ ("P")("U")("S")("H")($push\_code$);
  $load3$ ("P")("O")("P")(pop_code);
  $load7$ ("S")("P")("E")("C")("I")("A")("L")($special\_code$);
  $load10$ ("S")("P")("E")("C")("I")("A")("L")("H")("E")("X")($special\_hex\_code$);

This code is used in section 180.

57. ⟨ Enter the parameter names 57 ⟩ ≡

$load5$ ("S")("L")("A")("N")("T")($parameter\_code + 1$);
$load5$ ("S")("P")("A")("C")("E")($parameter\_code + 2$);
$load7$ ("S")("T")("R")("E")("T")("C")("H")($parameter\_code + 3$);
$load6$ ("S")("H")("R")("I")("N")("K")($parameter\_code + 4$);
$load7$ ("X")("H")("E")("I")("G")("H")("T")($parameter\_code + 5$);
$load4$ ("Q")("U")("A")("D")($parameter\_code + 6$);
$load10$ ("E")("X")("T")("R")("A")("S")("P")("A")("C")("E")($parameter\_code + 7$);
$load4$ ("N")("U")("M")("1")($parameter\_code + 8$);
$load4$ ("N")("U")("M")("2")($parameter\_code + 9$);
$load4$ ("N")("U")("M")("3")($parameter\_code + 10$);
$load6$ ("D")("E")("N")("O")("M")("1")($parameter\_code + 11$);
$load6$ ("D")("E")("N")("O")("M")("2")($parameter\_code + 12$);
$load4$ ("S")("U")("P")("1")($parameter\_code + 13$);
$load4$ ("S")("U")("P")("2")($parameter\_code + 14$);
$load4$ ("S")("U")("P")("3")($parameter\_code + 15$);
$load4$ ("S")("U")("B")("1")($parameter\_code + 16$);
$load4$ ("S")("U")("B")("2")($parameter\_code + 17$);
$load7$ ("S")("U")("P")("D")("R")("O")("P")($parameter\_code + 18$);
$load7$ ("S")("U")("B")("D")("R")("O")("P")($parameter\_code + 19$);
$load6$ ("D")("E")("L")("I")("M")("1")($parameter\_code + 20$);
$load6$ ("D")("E")("L")("I")("M")("2")($parameter\_code + 21$);
$load10$ ("A")("X")("I")("S")("H")("E")("I")("G")("H")("T")($parameter\_code + 22$);
$load20$ ("D")("E")("F")("A")("U")("L")("T")("R")("U")("L")("E")
  ("T")("H")("I")("C")("K")("N")("E")("S")("S")($parameter\_code + 8$);
$load13$ ("B")("I")("G")("O")("P")("S")("P")("A")("C")("I")("N")("G")("1")($parameter\_code + 9$);
$load13$ ("B")("I")("G")("O")("P")("S")("P")("A")("C")("I")("N")("G")("2")($parameter\_code + 10$);
$load13$ ("B")("I")("G")("O")("P")("S")("P")("A")("C")("I")("N")("G")("3")($parameter\_code + 11$);
$load13$ ("B")("I")("G")("O")("P")("S")("P")("A")("C")("I")("N")("G")("4")($parameter\_code + 12$);
$load13$ ("B")("I")("G")("O")("P")("S")("P")("A")("C")("I")("N")("G")("5")($parameter\_code + 13$);

This code is used in section 180.

58. When a left parenthesis has been scanned, the following routine is used to interpret the keyword that follows, and to store the equivalent value in cur_code.

procedure get_name;
  begin $incr(loc)$; $incr(level)$;   { pass the left parenthesis }
  $cur\_char \leftarrow$ "␣";
  while $cur\_char =$ "␣" **do** get_next;
  if $(cur\_char >$ ")"$) \vee (cur\_char <$ "("$)$ **then** $decr(loc)$;   { back up one character }
  $name\_length \leftarrow 0$; $get\_keyword\_char$;   { prepare to scan the name }
  while $cur\_char \neq$ "␣" **do**
    begin if $name\_length = longest\_name$ **then** $cur\_name[1] \leftarrow$ "X"   { force error }
    else $incr(name\_length)$;
    $cur\_name[name\_length] \leftarrow cur\_char$; $get\_keyword\_char$;
    end;
  $lookup$;
  if $name\_ptr = 0$ **then** $err\_print($´Sorry,␣I␣don´´t␣know␣that␣property␣name´$)$;
  $cur\_code \leftarrow equiv[name\_ptr]$;
  end;

59. Scanning numeric data. The next thing we need is a trio of subroutines to read the one-byte, four-byte, and real numbers that may appear as property values. These subroutines are careful to stick to numbers between -2^{31} and $2^{31} - 1$, inclusive, so that a computer with two's complement 32-bit arithmetic will not be interrupted by overflow.

60.   The first number scanner, which returns a one-byte value, surely has no problems of arithmetic overflow.

function *get_byte*: *byte*;   { scans a one-byte property value }
  var *acc*: *integer*;   { an accumulator }
    t: *ASCII_code*;   { the type of value to be scanned }
  begin repeat *get_next*;
  until *cur_char* ≠ "␣";   { skip the blanks before the type code }
  t ← *cur_char*; *acc* ← 0;
  repeat *get_next*;
  until *cur_char* ≠ "␣";   { skip the blanks after the type code }
  if *t* = "C" **then** ⟨ Scan an ASCII character code 61 ⟩
  else if *t* = "D" **then** ⟨ Scan a small decimal number 62 ⟩
    else if *t* = "O" **then** ⟨ Scan a small octal number 63 ⟩
      else if *t* = "H" **then** ⟨ Scan a small hexadecimal number 64 ⟩
        else if *t* = "F" **then** ⟨ Scan a face code 65 ⟩
          else *skip_error*(´You␣need␣"C"␣or␣"D"␣or␣"O"␣or␣"H"␣or␣"F"␣here´);
  cur_char ← "␣"; *get_byte* ← *acc*;
  end;

61.   The *get_next* routine converts lower case to upper case, but it leaves the character in the buffer, so we can unconvert it.

⟨ Scan an ASCII character code 61 ⟩ ≡
  if (*cur_char* ≥ ´41) ∧ (*cur_char* ≤ ´176) ∧ ((*cur_char* < "(") ∨ (*cur_char* > ")")) **then**
    acc ← *xord*[*buffer*[*loc*]]
  else *skip_error*(´"C"␣value␣must␣be␣standard␣ASCII␣and␣not␣a␣paren´)
This code is used in section 60.

62.   ⟨ Scan a small decimal number 62 ⟩ ≡
  begin while (*cur_char* ≥ "0") ∧ (*cur_char* ≤ "9") **do**
    begin *acc* ← *acc* ∗ 10 + *cur_char* − "0";
    if *acc* > 255 **then**
      begin *skip_error*(´This␣value␣shouldn´´t␣exceed␣255´); *acc* ← 0; *cur_char* ← "␣";
      end
    else *get_next*;
    end;
  backup;
  end
This code is used in section 60.

63. ⟨ Scan a small octal number 63 ⟩ ≡
  begin while $(cur\_char \geq$ "0"$) \wedge (cur\_char \leq$ "7"$)$ **do**
    begin $acc \leftarrow acc * 8 + cur\_char -$ "0";
    if $acc > 255$ **then**
      begin $skip\_error($´This␣value␣shouldn´´t␣exceed␣´´377´$);\ acc \leftarrow 0;\ cur\_char \leftarrow$ "␣";
      end
    else get_next;
    end;
  $backup$;
  end

This code is used in section 60.

64. ⟨ Scan a small hexadecimal number 64 ⟩ ≡
  begin while $((cur\_char \geq$ "0"$) \wedge (cur\_char \leq$ "9"$)) \vee ((cur\_char \geq$ "A"$) \wedge (cur\_char \leq$ "F"$))$ **do**
    begin if $cur\_char \geq$ "A" **then** $cur\_char \leftarrow cur\_char +$ "0" $+ 10 -$ "A";
    $acc \leftarrow acc * 16 + cur\_char -$ "0";
    if $acc > 255$ **then**
      begin $skip\_error($´This␣value␣shouldn´´t␣exceed␣"FF"´$);\ acc \leftarrow 0;\ cur\_char \leftarrow$ "␣";
      end
    else get_next;
    end;
  $backup$;
  end

This code is used in section 60.

65. ⟨ Scan a face code 65 ⟩ ≡
  begin if $cur\_char =$ "B" **then** $acc \leftarrow 2$
  else if $cur\_char =$ "L" **then** $acc \leftarrow 4$
    else if $cur\_char \neq$ "M" **then** $acc \leftarrow 18$;
  get_next;
  if $cur\_char =$ "I" **then** $incr(acc)$
  else if $cur\_char \neq$ "R" **then** $acc \leftarrow 18$;
  get_next;
  if $cur\_char =$ "C" **then** $acc \leftarrow acc + 6$
  else if $cur\_char =$ "E" **then** $acc \leftarrow acc + 12$
    else if $cur\_char \neq$ "R" **then** $acc \leftarrow 18$;
  if $acc \geq 18$ **then**
    begin $skip\_error($´Illegal␣face␣code,␣I␣changed␣it␣to␣MRR´$);\ acc \leftarrow 0$;
    end;
  end

This code is used in section 60.

66. The routine that scans a four-byte value puts its output into cur_bytes, which is a record containing (yes, you guessed it) four bytes.

⟨ Types in the outer block 23 ⟩ +≡
  $four\_bytes =$ **record** $b0$: $byte$; $b1$: $byte$; $b2$: $byte$; $b3$: $byte$;
    end;

67.   **define** $c0 \equiv cur\_bytes.b0$
  define $c1 \equiv cur\_bytes.b1$
  define $c2 \equiv cur\_bytes.b2$
  define $c3 \equiv cur\_bytes.b3$

⟨ Globals in the outer block 5 ⟩ +≡
cur_bytes: $four\_bytes$;   { a four-byte accumulator }
$zero\_bytes$: $four\_bytes$;   { four bytes all zero }

68.   ⟨ Set initial values 6 ⟩ +≡
  $zero\_bytes.b0 \leftarrow 0$; $zero\_bytes.b1 \leftarrow 0$; $zero\_bytes.b2 \leftarrow 0$; $zero\_bytes.b3 \leftarrow 0$;

69.   Since the get_four_bytes routine is used very infrequently, no attempt has been made to make it fast;
we only want it to work.

procedure get_four_bytes;   { scans an unsigned constant and sets $four\_bytes$ }
  var c: $integer$;   { local two-byte accumulator }
    r: $integer$;   { radix }
  begin repeat get_next;
  until $cur\_char \neq$ "␣";   { skip the blanks before the type code }
  $r \leftarrow 0$; $cur\_bytes \leftarrow zero\_bytes$;   { start with the accumulator zero }
  if $cur\_char =$ "H" **then** $r \leftarrow 16$
  else if $cur\_char =$ "O" **then** $r \leftarrow 8$
    else if $cur\_char =$ "D" **then** $r \leftarrow 10$
      else $skip\_error$(´Decimal␣("D"),␣octal␣("O"),␣or␣hex␣("H")␣value␣needed␣here´);
  if $r > 0$ **then**
    begin repeat get_next;
    until $cur\_char \neq$ "␣";   { skip the blanks after the type code }
    while $((cur\_char \geq$ "0"$) \wedge (cur\_char \leq$ "9"$)) \vee ((cur\_char \geq$ "A"$) \wedge (cur\_char \leq$ "F"$))$ **do**
      ⟨ Multiply by r, add $cur\_char -$ "0", and get_next 70 ⟩;
    end;
  end;

70.   ⟨ Multiply by r, add $cur\_char -$ "0", and get_next 70 ⟩ ≡
  begin if $cur\_char \geq$ "A" **then** $cur\_char \leftarrow cur\_char +$ "0" $+ 10 -$ "A";
  if $cur\_char \geq$ "0" $+ r$ **then** $skip\_error$(´Illegal␣digit´)
  else begin $c \leftarrow c3 * r + cur\_char -$ "0"; $c3 \leftarrow c \bmod 256$;
    $c \leftarrow c2 * r + c \mathbf{div}\ 256$; $c2 \leftarrow c \bmod 256$;
    $c \leftarrow c1 * r + c \mathbf{div}\ 256$; $c1 \leftarrow c \bmod 256$;
    $c \leftarrow c0 * r + c \mathbf{div}\ 256$;
    if $c < 256$ **then** $c0 \leftarrow c$
    else begin $cur\_bytes \leftarrow zero\_bytes$;
      if $r = 8$ **then** $skip\_error$(´Sorry,␣the␣maximum␣octal␣value␣is␣O␣37777777777´)
      else if $r = 10$ **then** $skip\_error$(´Sorry,␣the␣maximum␣decimal␣value␣is␣D␣4294967295´)
        else $skip\_error$(´Sorry,␣the␣maximum␣hex␣value␣is␣H␣FFFFFFFF´);
      end;
    get_next;
    end;
  end

This code is used in section 69.

71.   The remaining scanning routine is the most interesting. It scans a real constant and returns the nearest *fix_word* approximation to that constant. A *fix_word* is a 32-bit integer that represents a real value that has been multiplied by 2^{20}. Since VPtoVF restricts the magnitude of reals to 2048, the *fix_word* will have a magnitude less than 2^{31}.

> **define** *unity* $\equiv$ ´4000000   { 2^{20}, the *fix_word* 1.0 }

⟨ Types in the outer block 23 ⟩ +≡
  fix_word = *integer*;   { a scaled real value with 20 bits of fraction }

72.   When a real value is desired, we might as well treat 'D' and 'R' formats as if they were identical.

function *get_fix*: *fix_word*;   { scans a real property value }
  var *negative*: *boolean*;   { was there a minus sign? }
    acc: *integer*;   { an accumulator }
    int_part: *integer*;   { the integer part }
    j: 0 . . 7;   { the number of decimal places stored }
  begin repeat *get_next*;
  until *cur_char* ≠ "␣";   { skip the blanks before the type code }
  negative ← *false*; *acc* ← 0;   { start with the accumulators zero }
  if (*cur_char* ≠ "R") ∧ (*cur_char* ≠ "D") **then** *skip_error*(´An␣"R"␣or␣"D"␣value␣is␣needed␣here´)
  else begin ⟨ Scan the blanks and/or signs after the type code 73 ⟩;
    while (*cur_char* ≥ "0") ∧ (*cur_char* ≤ "9") **do** ⟨ Multiply by 10, add *cur_char* − "0", and *get_next* 74 ⟩;
    int_part ← *acc*; *acc* ← 0;
    if *cur_char* = "." **then** ⟨ Scan the fraction part and put it in *acc* 76 ⟩;
    if (*acc* ≥ *unity*) ∧ (*int_part* = 2047) **then** *skip_error*(´Real␣constants␣must␣be␣less␣than␣2048´)
    else *acc* ← *int_part* ∗ *unity* + *acc*;
    end;
  if *negative* **then** *get_fix* ← −*acc* **else** *get_fix* ← *acc*;
  end;

73.   ⟨ Scan the blanks and/or signs after the type code 73 ⟩ ≡
  repeat *get_next*;
    if *cur_char* = "-" **then**
      begin *cur_char* ← "␣"; *negative* ← *true*;
      end
    else if *cur_char* = "+" **then** *cur_char* ← "␣";
  until *cur_char* ≠ "␣"
This code is used in section 72.

74.   ⟨ Multiply by 10, add *cur_char* − "0", and *get_next* 74 ⟩ ≡
  begin *acc* ← *acc* ∗ 10 + *cur_char* − "0";
  if *acc* ≥ 2048 **then**
    begin *skip_error*(´Real␣constants␣must␣be␣less␣than␣2048´); *acc* ← 0; *cur_char* ← "␣";
    end
  else *get_next*;
  end
This code is used in section 72.

75.   To scan the fraction $.d_1 d_2 \ldots$, we keep track of up to seven of the digits d_j. A correct result is obtained if we first compute $f' = \lfloor 2^{21}(d_1 \ldots d_j)/10^j \rfloor$, after which $f = \lfloor (f' + 1)/2 \rfloor$. It is possible to have $f = 1.0$.

⟨ Globals in the outer block 5 ⟩ +≡
fraction_digits: **array** [1 . . 7] **of** *integer*;   { 2^{21} times d_j }

76. ⟨ Scan the fraction part and put it in *acc* 76 ⟩ ≡
  begin $j \leftarrow 0$; *get_next*;
  while $(cur\_char \geq$ "0"$) \wedge (cur\_char \leq$ "9"$)$ **do**
    begin if $j < 7$ **then**
      begin $incr(j)$; $fraction\_digits[j] \leftarrow$ ´10000000 $* (cur\_char -$ "0"$)$;
      end;
    get_next;
    end;
  $acc \leftarrow 0$;
  while $j > 0$ **do**
    begin $acc \leftarrow fraction\_digits[j] + (acc$ **div** $10)$; $decr(j)$;
    end;
  $acc \leftarrow (acc + 10)$ **div** 20;
  end

This code is used in section 72.

77. Storing the property values.   When property values have been found, they are squirreled away in a bunch of arrays. The header information is unpacked into bytes in an array called *header_bytes*. The ligature/kerning program is stored in an array of type *four_bytes*. Another *four_bytes* array holds the specifications of extensible characters. The kerns and parameters are stored in separate arrays of *fix_word* values. Virtual font data goes into an array *vf* of single-byte values.

We maintain information about at most 256 local fonts. (If this is inadequate, several arrays need to be made longer and we need to output font definitions that go beyond *fnt1* and *fnt_def1* in the VF file.)

Instead of storing the design size in the header array, we will keep it in a *fix_word* variable until the last minute. The number of units in the design size is also kept in a *fix_word*.

⟨ Globals in the outer block 5 ⟩ +≡
header_bytes: **array** [*header_index*] **of** *byte*;   { the header block }
header_ptr: *header_index*;   { the number of header bytes in use }
design_size: *fix_word*;   { the design size }
design_units: *fix_word*;   { reciprocal of the scaling factor }
frozen_du: *boolean*;   { have we used *design_units* irrevocably? }
seven_bit_safe_flag: *boolean*;   { does the file claim to be seven-bit-safe? }
lig_kern: **array** [0 . . *max_lig_steps*] **of** *four_bytes*;   { the ligature program }
nl: 0 . . 32767;   { the number of ligature/kern instructions so far }
min_nl: 0 . . 32767;   { the final value of *nl* must be at least this }
kern: **array** [0 . . *max_kerns*] **of** *fix_word*;   { the distinct kerning amounts }
nk: 0 . . *max_kerns*;   { the number of entries of *kern* }
exten: **array** [0 . . 255] **of** *four_bytes*;   { extensible character specs }
ne: 0 . . 256;   { the number of extensible characters }
param: **array** [1 . . *max_param_words*] **of** *fix_word*;   { FONTDIMEN parameters }
np: 0 . . *max_param_words*;   { the largest parameter set nonzero }
check_sum_specified: *boolean*;   { did the user name the check sum? }
bchar: 0 . . 256;   { the right boundary character, or 256 if unspecified }
vf: **array** [0 . . *vf_size*] **of** *byte*;   { stored bytes for VF file }
vf_ptr: 0 . . *vf_size*;   { first unused location in *vf* }
vtitle_start: 0 . . *vf_size*;   { starting location of VTITLE string }
vtitle_length: *byte*;   { length of VTITLE string }
packet_start: **array** [*byte*] **of** 0 . . *vf_size*;   { beginning location of character packet }
packet_length: **array** [*byte*] **of** *integer*;   { length of character packet }
font_ptr: 0 . . 256;   { number of distinct local fonts seen }
cur_font: 0 . . 256;   { number of the current local font }
fname_start: **array** [*byte*] **of** 0 . . *vf_size*;   { beginning of local font name }
fname_length: **array** [*byte*] **of** *byte*;   { length of local font name }
farea_start: **array** [*byte*] **of** 0 . . *vf_size*;   { beginning of local font area }
farea_length: **array** [*byte*] **of** *byte*;   { length of local font area }
font_checksum: **array** [*byte*] **of** *four_bytes*;   { local font checksum }
font_number: **array** [0 . . 256] **of** *four_bytes*;   { local font id number }
font_at: **array** [*byte*] **of** *fix_word*;   { local font "at size" }
font_dsize: **array** [*byte*] **of** *fix_word*;   { local font design size }

78.   ⟨ Types in the outer block 23 ⟩ +≡
  header_index = 0 . . *max_header_bytes*; *indx* = 0 . . ´77777;

79.   ⟨ Local variables for initialization 25 ⟩ +≡
d: *header_index*;   { an index into *header_bytes* }

80.   We start by setting up the default values.

  define $check\_sum\_loc = 0$
  define $design\_size\_loc = 4$
  define $coding\_scheme\_loc = 8$
  define $family\_loc = coding\_scheme\_loc + 40$
  define $seven\_flag\_loc = family\_loc + 20$
  define $face\_loc = seven\_flag\_loc + 3$

⟨ Set initial values 6 ⟩ +≡
  for $d \leftarrow 0$ **to** $18 * 4 - 1$ **do** $header\_bytes[d] \leftarrow 0$;
  $header\_bytes[8] \leftarrow 11$; $header\_bytes[9] \leftarrow$ "U"; $header\_bytes[10] \leftarrow$ "N"; $header\_bytes[11] \leftarrow$ "S";
  $header\_bytes[12] \leftarrow$ "P"; $header\_bytes[13] \leftarrow$ "E"; $header\_bytes[14] \leftarrow$ "C"; $header\_bytes[15] \leftarrow$ "I";
  $header\_bytes[16] \leftarrow$ "F"; $header\_bytes[17] \leftarrow$ "I"; $header\_bytes[18] \leftarrow$ "E"; $header\_bytes[19] \leftarrow$ "D";
  for $d \leftarrow family\_loc$ **to** $family\_loc + 11$ **do** $header\_bytes[d] \leftarrow header\_bytes[d - 40]$;
  $design\_size \leftarrow 10 * unity$; $design\_units \leftarrow unity$; $frozen\_du \leftarrow false$; $seven\_bit\_safe\_flag \leftarrow false$;
  $header\_ptr \leftarrow 18 * 4$; $nl \leftarrow 0$; $min\_nl \leftarrow 0$; $nk \leftarrow 0$; $ne \leftarrow 0$; $np \leftarrow 0$;
  $check\_sum\_specified \leftarrow false$; $bchar \leftarrow 256$;
  $vf\_ptr \leftarrow 0$; $vtitle\_start \leftarrow 0$; $vtitle\_length \leftarrow 0$; $font\_ptr \leftarrow 0$;
  for $k \leftarrow 0$ **to** 255 **do** $packet\_start[k] \leftarrow vf\_size$;
  for $k \leftarrow 0$ **to** 127 **do** $packet\_length[k] \leftarrow 1$;
  for $k \leftarrow 128$ **to** 255 **do** $packet\_length[k] \leftarrow 2$;

81.   Most of the dimensions, however, go into the *memory* array. There are at most 257 widths, 257 heights, 257 depths, and 257 italic corrections, since the value 0 is required but it need not be used. So *memory* has room for 1028 entries, each of which is a *fix_word*. An auxiliary table called *link* is used to link these words together in linear lists, so that sorting and other operations can be done conveniently.

   We also add four "list head" words to the *memory* and *link* arrays; these are in locations *width* through *italic*, i.e., 1 through 4. For example, *link*[*height*] points to the smallest element in the sorted list of distinct heights that have appeared so far, and *memory*[*height*] is the number of distinct heights.

  define $mem\_size = 1028 + 4$ { number of nonzero memory addresses }

⟨ Types in the outer block 23 ⟩ +≡
  $pointer = 0 \mathinner{.\,.} mem\_size$;   { an index into memory }

82.   The arrays *char_wd*, *char_ht*, *char_dp*, and *char_ic* contain pointers to the *memory* array entries where the corresponding dimensions appear. Two other arrays, *char_tag* and *char_remainder*, hold the other information that TFM files pack into a *char_info_word*.

  define $no\_tag = 0$ { vanilla character }
  define $lig\_tag = 1$ { character has a ligature/kerning program }
  define $list\_tag = 2$ { character has a successor in a charlist }
  define $ext\_tag = 3$ { character is extensible }
  define $bchar\_label \equiv char\_remainder[256]$ { beginning of ligature program for left boundary }

⟨ Globals in the outer block 5 ⟩ +≡
$memory$: **array** [$pointer$] **of** fix_word;   { character dimensions and kerns }
mem_ptr: $pointer$;   { largest *memory* word in use }
$link$: **array** [$pointer$] **of** $pointer$;   { to make lists of *memory* items }
$char\_wd$: **array** [$byte$] **of** $pointer$;   { pointers to the widths }
$char\_ht$: **array** [$byte$] **of** $pointer$;   { pointers to the heights }
$char\_dp$: **array** [$byte$] **of** $pointer$;   { pointers to the depths }
$char\_ic$: **array** [$byte$] **of** $pointer$;   { pointers to italic corrections }
$char\_tag$: **array** [$byte$] **of** $no\_tag \mathinner{.\,.} ext\_tag$;   { character tags }
$char\_remainder$: **array** [$0 \mathinner{.\,.} 256$] **of** $0 \mathinner{.\,.} 65535$;
          { pointers to ligature labels, next larger characters, or extensible characters }

83. ⟨ Local variables for initialization 25 ⟩ +≡
c: *byte*;   { runs through all character codes }

84. ⟨ Set initial values 6 ⟩ +≡
  bchar_label ← ´77777;
  for *c* ← 0 **to** 255 **do**
      begin *char_wd*[*c*] ← 0; *char_ht*[*c*] ← 0; *char_dp*[*c*] ← 0; *char_ic*[*c*] ← 0;
      char_tag[*c*] ← *no_tag*; *char_remainder*[*c*] ← 0;
      end;
  memory[0] ← ´17777777777;   { an "infinite" element at the end of the lists }
  memory[*width*] ← 0; *link*[*width*] ← 0;   { width list is empty }
  memory[*height*] ← 0; *link*[*height*] ← 0;   { height list is empty }
  memory[*depth*] ← 0; *link*[*depth*] ← 0;   { depth list is empty }
  memory[*italic*] ← 0; *link*[*italic*] ← 0;   { italic list is empty }
  mem_ptr ← *italic*;

85.   As an example of these data structures, let us consider the simple routine that inserts a potentially new element into one of the dimension lists. The first parameter indicates the list head (i.e., $h = width$ for the width list, etc.); the second parameter is the value that is to be inserted into the list if it is not already present. The procedure returns the value of the location where the dimension appears in *memory*. The fact that *memory*[0] is larger than any legal dimension makes the algorithm particularly short.

  We do have to handle two somewhat subtle situations. A width of zero must be put into the list, so that a zero-width character in the font will not appear to be nonexistent (i.e., so that its *char_wd* index will not be zero), but this does not need to be done for heights, depths, or italic corrections. Furthermore, it is necessary to test for memory overflow even though we have provided room for the maximum number of different dimensions in any legal font, since the VPL file might foolishly give any number of different sizes to the same character.

function *sort_in*(*h* : *pointer*; *d* : *fix_word*): *pointer*;   { inserts into list }
  var *p*: *pointer*;   { the current node of interest }
  begin if $(d = 0) \land (h \neq width)$ **then** *sort_in* ← 0
  else begin *p* ← *h*;
      while $d \geq memory[link[p]]$ **do** *p* ← *link*[*p*];
      if $(d = memory[p]) \land (p \neq h)$ **then** *sort_in* ← *p*
      else if *mem_ptr* = *mem_size* **then**
          begin *err_print*(´Memory␣overflow:␣more␣than␣1028␣widths,␣etc´);
          print_ln(´Congratulations!␣It´´s␣hard␣to␣make␣this␣error.´); *sort_in* ← *p*;
          end
        else begin *incr*(*mem_ptr*); *memory*[*mem_ptr*] ← *d*; *link*[*mem_ptr*] ← *link*[*p*]; *link*[*p*] ← *mem_ptr*;
          incr(*memory*[*h*]); *sort_in* ← *mem_ptr*;
          end;
      end;
  end;

86.   When these lists of dimensions are eventually written to the `TFM` file, we may have to do some rounding of values, because the `TFM` file allows at most 256 widths, 16 heights, 16 depths, and 64 italic corrections. The following procedure takes a given list head h and a given dimension d, and returns the minimum m such that the elements of the list can be covered by m intervals of width d. It also sets $next\_d$ to the smallest value $d' > d$ such that the covering found by this procedure would be different. In particular, if $d = 0$ it computes the number of elements of the list, and sets $next\_d$ to the smallest distance between two list elements. (The covering by intervals of width $next\_d$ is not guaranteed to have fewer than m elements, but in practice this seems to happen most of the time.)

⟨ Globals in the outer block 5 ⟩ +≡
$next\_d$: fix_word;   { the next larger interval that is worth trying }

87.   Once again we can make good use of the fact that $memory[0]$ is "infinite."

function $min\_cover\,(h : pointer;\; d : fix\_word)$: $integer$;
  var p: $pointer$;   { the current node of interest }
    l: fix_word;   { the least element covered by the current interval }
    m: $integer$;   { the current size of the cover being generated }
  begin $m \leftarrow 0$; $p \leftarrow link[h]$; $next\_d \leftarrow memory[0]$;
  while $p \neq 0$ **do**
    begin $incr(m)$; $l \leftarrow memory[p]$;
    while $memory[link[p]] \leq l + d$ **do** $p \leftarrow link[p]$;
    $p \leftarrow link[p]$;
    if $memory[p] - l < next\_d$ **then** $next\_d \leftarrow memory[p] - l$;
    end;
  $min\_cover \leftarrow m$;
  end;

88.   The following procedure uses min_cover to determine the smallest d such that a given list can be covered with at most a given number of intervals.

function $shorten\,(h : pointer;\; m : integer)$: fix_word;   { finds best way to round }
  var d: fix_word;   { the current trial interval length }
    k: $integer$;   { the size of a minimum cover }
  begin if $memory[h] > m$ **then**
    begin $excess \leftarrow memory[h] - m$; $k \leftarrow min\_cover(h, 0)$; $d \leftarrow next\_d$;   { now the answer is at least d }
    repeat $d \leftarrow d + d$; $k \leftarrow min\_cover(h, d)$;
    until $k \leq m$;   { first we ascend rapidly until finding the range }
    $d \leftarrow d$ **div** 2; $k \leftarrow min\_cover(h, d)$;   { now we run through the feasible steps }
    while $k > m$ **do**
      begin $d \leftarrow next\_d$; $k \leftarrow min\_cover(h, d)$;
      end;
    $shorten \leftarrow d$;
    end
  else $shorten \leftarrow 0$;
  end;

89.   When we are nearly ready to output the `TFM` file, we will set $index[p] \leftarrow k$ if the dimension in $memory[p]$ is being rounded to the kth element of its list.

⟨ Globals in the outer block 5 ⟩ +≡
$index$: **array** $[pointer]$ **of** $byte$;
$excess$: $byte$;   { number of words to remove, if list is being shortened }

90.   Here is the procedure that sets the *index* values. It also shortens the list so that there is only one element per covering interval; the remaining elements are the midpoints of their clusters.

procedure *set_indices*(*h* : *pointer*; *d* : *fix_word*);   { reduces and indexes a list }
  var *p*: *pointer*;   { the current node of interest }
    q: *pointer*;   { trails one step behind *p* }
    m: *byte*;   { index number of nodes in the current interval }
    l: *fix_word*;   { least value in the current interval }
  begin $q \leftarrow h$; $p \leftarrow link[q]$; $m \leftarrow 0$;
  while $p \neq 0$ **do**
    begin *incr*(*m*); $l \leftarrow memory[p]$; $index[p] \leftarrow m$;
    while $memory[link[p]] \leq l + d$ **do**
      begin $p \leftarrow link[p]$; $index[p] \leftarrow m$; *decr*(*excess*);
      if $excess = 0$ **then** $d \leftarrow 0$;
      end;
    $link[q] \leftarrow p$; $memory[p] \leftarrow l + (memory[p] - l)$ **div** 2; $q \leftarrow p$; $p \leftarrow link[p]$;
    end;
  $memory[h] \leftarrow m$;
  end;

91.   The input phase.   We're ready now to read and parse the VPL file, storing property values as we go.

⟨ Globals in the outer block 5 ⟩ +≡
c: *byte*;   { the current character or byte being processed }
x: *fix_word*;   { current dimension of interest }
k: *integer*;   { general-purpose index }

92.   ⟨ Read all the input 92 ⟩ ≡
  cur_char ← "␣";
  repeat while *cur_char* = "␣" **do** *get_next*;
    if *cur_char* = "(" **then** ⟨ Read a font property value 94 ⟩
    else if (*cur_char* = ")") ∧ ¬*input_has_ended* **then**
        begin *err_print*(´Extra␣right␣parenthesis´); *incr*(*loc*); *cur_char* ← "␣";
        end
      else if ¬*input_has_ended* **then** *junk_error*;
  until *input_has_ended*

This code is used in section 180.

93.   The *junk_error* routine just referred to is called when something appears in the forbidden area between properties of a property list.

procedure *junk_error*;   { gets past no man's land }
  begin *err_print*(´There´´s␣junk␣here␣that␣is␣not␣in␣parentheses´); *skip_to_paren*;
  end;

94.   For each font property, we are supposed to read the data from the left parenthesis that is the current value of *cur_char* to the right parenthesis that matches it in the input. The main complication is to recover with reasonable grace from various error conditions that might arise.

⟨ Read a font property value 94 ⟩ ≡
  begin *get_name*;
  if *cur_code* = *comment_code* **then** *skip_to_end_of_item*
  else if *cur_code* > *character_code* **then**
      flush_error(´This␣property␣name␣doesn´´t␣belong␣on␣the␣outer␣level´)
    else begin ⟨ Read the font property value specified by *cur_code* 95 ⟩;
      finish_the_property;
      end;
  end

This code is used in section 92.

95. ⟨Read the font property value specified by *cur_code* 95⟩ ≡
  case *cur_code* **of**
  check_sum_code: **begin** *check_sum_specified* ← *true*; *read_four_bytes*(*check_sum_loc*);
    end;
  design_size_code: ⟨Read the design size 98⟩;
  design_units_code: ⟨Read the design units 99⟩;
  coding_scheme_code: *read_BCPL*(*coding_scheme_loc*, 40);
  family_code: *read_BCPL*(*family_loc*, 20);
  face_code: *header_bytes*[*face_loc*] ← *get_byte*;
  seven_bit_safe_flag_code: ⟨Read the seven-bit-safe flag 100⟩;
  header_code: ⟨Read an indexed header word 101⟩;
  font_dimen_code: ⟨Read font parameter list 102⟩;
  lig_table_code: *read_lig_kern*;
  boundary_char_code: *bchar* ← *get_byte*;
  virtual_title_code: **begin** *vtitle_start* ← *vf_ptr*; *copy_to_end_of_item*;
    if *vf_ptr* > *vtitle_start* + 255 **then**
      begin *err_print*(´VTITLE␣clipped␣to␣255␣characters´); *vtitle_length* ← 255;
      end
    else *vtitle_length* ← *vf_ptr* − *vtitle_start*;
    end;
  map_font_code: ⟨Read a local font list 104⟩;
  character_code: *read_char_info*;
  end
This code is used in section 94.

96. The **case** statement just given makes use of three subroutines that we haven't defined yet. The first
of these puts a 32-bit octal quantity into four specified bytes of the header block.

procedure *read_four_bytes*(*l* : *header_index*);
  begin *get_four_bytes*; *header_bytes*[*l*] ← *c0*; *header_bytes*[*l* + 1] ← *c1*; *header_bytes*[*l* + 2] ← *c2*;
  header_bytes[*l* + 3] ← *c3*;
  end;

97. The second little procedure is used to scan a string and to store it in the "BCPL format" required by
TFM files. The string is supposed to contain at most n bytes, including the first byte (which holds the length
of the rest of the string).

procedure $read\_BCPL(l : header\_index; n : byte);$
  var k: $header\_index;$
  begin $k \leftarrow l;$
  while $cur\_char =$ "␣" **do** $get\_next;$
  while $(cur\_char \neq$ "(") $\wedge (cur\_char \neq$ ")") **do**
    begin if $k < l + n$ **then** $incr(k);$
    if $k < l + n$ **then** $header\_bytes[k] \leftarrow cur\_char;$
    $get\_next;$
    end;
  if $k = l + n$ **then**
    begin $err\_print($´String␣is␣too␣long;␣its␣first␣´$, n - 1 : 1,$ ´␣characters␣will␣be␣kept´$);$
    $decr(k);$
    end;
  $header\_bytes[l] \leftarrow k - l;$
  while $k < l + n - 1$ **do**   { tidy up the remaining bytes by setting them to nulls }
    begin $incr(k);$ $header\_bytes[k] \leftarrow 0;$
    end;
  end;

98. ⟨ Read the design size 98 ⟩ ≡
  begin $next\_d \leftarrow get\_fix;$
  if $next\_d < unity$ **then** $err\_print($´The␣design␣size␣must␣be␣at␣least␣1´$)$
  else $design\_size \leftarrow next\_d;$
  end

This code is used in section 95.

99. ⟨ Read the design units 99 ⟩ ≡
  begin $next\_d \leftarrow get\_fix;$
  if $next\_d \leq 0$ **then** $err\_print($´The␣number␣of␣units␣per␣design␣size␣must␣be␣positive´$)$
  else if $frozen\_du$ **then** $err\_print($´Sorry,␣it´´s␣too␣late␣to␣change␣the␣design␣units´$)$
    else $design\_units \leftarrow next\_d;$
  end

This code is used in section 95.

100. ⟨ Read the seven-bit-safe flag 100 ⟩ ≡
  begin while $cur\_char =$ "␣" **do** $get\_next;$
  if $cur\_char =$ "T" **then** $seven\_bit\_safe\_flag \leftarrow true$
  else if $cur\_char =$ "F" **then** $seven\_bit\_safe\_flag \leftarrow false$
    else $err\_print($´The␣flag␣value␣should␣be␣"TRUE"␣or␣"FALSE"´$);$
  $skip\_to\_paren;$
  end

This code is used in section 95.

101. ⟨Read an indexed header word 101⟩ ≡
  begin $c \leftarrow get\_byte$;
  if $c < 18$ **then** $skip\_error(\text{´HEADER}_\sqcup\text{indices}_\sqcup\text{should}_\sqcup\text{be}_\sqcup\text{18}_\sqcup\text{or}_\sqcup\text{more´})$
  else if $4 * c + 4 > max\_header\_bytes$ **then**
      $skip\_error(\text{´This}_\sqcup\text{HEADER}_\sqcup\text{index}_\sqcup\text{is}_\sqcup\text{too}_\sqcup\text{big}_\sqcup\text{for}_\sqcup\text{my}_\sqcup\text{present}_\sqcup\text{table}_\sqcup\text{size´})$
    else begin while $header\_ptr < 4 * c + 4$ **do**
        begin $header\_bytes[header\_ptr] \leftarrow 0$; $incr(header\_ptr)$;
        end;
      $read\_four\_bytes(4 * c)$;
      end;
  end

This code is used in section 95.

102.   The remaining kinds of font property values that need to be read are those that involve property lists on higher levels. Each of these has a loop similar to the one that was used at level zero. Then we put the right parenthesis back so that '*finish_the_property*' will be happy; there is probably a more elegant way to do this.

  define $finish\_inner\_property\_list \equiv$
          begin $decr(loc)$; $incr(level)$; $cur\_char \leftarrow \text{")"}$;
          end

⟨Read font parameter list 102⟩ ≡
  begin while $level = 1$ **do**
    begin while $cur\_char = \text{"}_\sqcup\text{"}$ **do** get_next;
    if $cur\_char = \text{"("}$ **then** ⟨Read a parameter value 103⟩
    else if $cur\_char = \text{")"}$ **then** $skip\_to\_end\_of\_item$
      else $junk\_error$;
    end;
  $finish\_inner\_property\_list$;
  end

This code is used in section 95.

103. ⟨Read a parameter value 103⟩ ≡
  begin get_name;
  if $cur\_code = comment\_code$ **then** $skip\_to\_end\_of\_item$
  else if $(cur\_code < parameter\_code) \vee (cur\_code \geq char\_wd\_code)$ **then**
      $flush\_error(\text{´This}_\sqcup\text{property}_\sqcup\text{name}_\sqcup\text{doesn´´t}_\sqcup\text{belong}_\sqcup\text{in}_\sqcup\text{a}_\sqcup\text{FONTDIMEN}_\sqcup\text{list´})$
    else begin if $cur\_code = parameter\_code$ **then** $c \leftarrow get\_byte$
      else $c \leftarrow cur\_code - parameter\_code$;
      if $c = 0$ **then** $flush\_error(\text{´PARAMETER}_\sqcup\text{index}_\sqcup\text{must}_\sqcup\text{not}_\sqcup\text{be}_\sqcup\text{zero´})$
      else if $c > max\_param\_words$ **then**
          $flush\_error(\text{´This}_\sqcup\text{PARAMETER}_\sqcup\text{index}_\sqcup\text{is}_\sqcup\text{too}_\sqcup\text{big}_\sqcup\text{for}_\sqcup\text{my}_\sqcup\text{present}_\sqcup\text{table}_\sqcup\text{size´})$
        else begin while $np < c$ **do**
            begin $incr(np)$; $param[np] \leftarrow 0$;
            end;
          $param[c] \leftarrow get\_fix$; $finish\_the\_property$;
          end;
      end;
  end

This code is used in section 102.

104. **define** $numbers\_differ \equiv (font\_number[cur\_font].b3 \neq font\_number[font\_ptr].b3) \vee$
$\qquad (font\_number[cur\_font].b2 \neq font\_number[font\_ptr].b2) \vee$
$\qquad (font\_number[cur\_font].b1 \neq font\_number[font\_ptr].b1) \vee$
$\qquad (font\_number[cur\_font].b0 \neq font\_number[font\_ptr].b0)$

$\langle$ Read a local font list 104 $\rangle \equiv$
  begin get_four_bytes; $font\_number[font\_ptr] \leftarrow cur\_bytes$; $cur\_font \leftarrow 0$;
  while $numbers\_differ$ **do** $incr(cur\_font)$;
  if $cur\_font = font\_ptr$ **then**   { it's a new font number }
    if $font\_ptr < 256$ **then** $\langle$ Initialize a new local font 105 $\rangle$
    else $err\_print(\text{´I}_\sqcup\text{can}_\sqcup\text{handle}_\sqcup\text{only}_\sqcup\text{256}_\sqcup\text{different}_\sqcup\text{mapfonts´})$;
  if $cur\_font = font\_ptr$ **then** $skip\_to\_end\_of\_item$
  else while $level = 1$ **do**
      begin while $cur\_char = "_\sqcup"$ **do** get_next;
      if $cur\_char = "("$ **then** $\langle$ Read a local font property 106 $\rangle$
      else if $cur\_char = ")"$ **then** $skip\_to\_end\_of\_item$
        else $junk\_error$;
      end;
  $finish\_inner\_property\_list$;
  end

This code is used in section 95.

105. $\langle$ Initialize a new local font 105 $\rangle \equiv$
  begin $incr(font\_ptr)$; $fname\_start[cur\_font] \leftarrow vf\_size$; $fname\_length[cur\_font] \leftarrow 4$; { NULL }
  $farea\_start[cur\_font] \leftarrow vf\_size$; $farea\_length[cur\_font] \leftarrow 0$; $font\_checksum[cur\_font] \leftarrow zero\_bytes$;
  $font\_at[cur\_font] \leftarrow \text{´}4000000$; { denotes design size of this virtual font }
  $font\_dsize[cur\_font] \leftarrow \text{´}50000000$;   { the fix_word for 10 }
  end

This code is used in section 104.

106. $\langle$ Read a local font property 106 $\rangle \equiv$
  begin get_name;
  if $cur\_code = comment\_code$ **then** $skip\_to\_end\_of\_item$
  else if $(cur\_code < font\_name\_code) \vee (cur\_code > font\_dsize\_code)$ **then**
      $flush\_error(\text{´This}_\sqcup\text{property}_\sqcup\text{name}_\sqcup\text{doesn´´t}_\sqcup\text{belong}_\sqcup\text{in}_\sqcup\text{a}_\sqcup\text{MAPFONT}_\sqcup\text{list´})$
    else begin case cur_code **of**
      $font\_name\_code$: $\langle$ Read a local font name 107 $\rangle$;
      $font\_area\_code$: $\langle$ Read a local font area 108 $\rangle$;
      $font\_checksum\_code$: **begin** get_four_bytes; $font\_checksum[cur\_font] \leftarrow cur\_bytes$;
        end;
      $font\_at\_code$: **begin** $frozen\_du \leftarrow true$;
        if $design\_units = unity$ **then** $font\_at[cur\_font] \leftarrow get\_fix$
        else $font\_at[cur\_font] \leftarrow round((get\_fix/design\_units) * 1048576.0)$;
        end;
      $font\_dsize\_code$: $font\_dsize[cur\_font] \leftarrow get\_fix$;
      end;   { there are no other cases }
      $finish\_the\_property$;
      end;
  end

This code is used in section 104.

107. ⟨Read a local font name 107⟩ ≡

  begin *fname_start*[*cur_font*] ← *vf_ptr*; *copy_to_end_of_item*;

  if *vf_ptr* > *fname_start*[*cur_font*] + 255 **then**

    begin *err_print*(ˊFONTNAME␣clipped␣to␣255␣charactersˊ); *fname_length*[*cur_font*] ← 255;

    end

  else *fname_length*[*cur_font*] ← *vf_ptr* − *fname_start*[*cur_font*];

  end

This code is used in section 106.

108. ⟨Read a local font area 108⟩ ≡

  begin *farea_start*[*cur_font*] ← *vf_ptr*; *copy_to_end_of_item*;

  if *vf_ptr* > *farea_start*[*cur_font*] + 255 **then**

    begin *err_print*(ˊFONTAREA␣clipped␣to␣255␣charactersˊ); *farea_length*[*cur_font*] ← 255;

    end

  else *farea_length*[*cur_font*] ← *vf_ptr* − *farea_start*[*cur_font*];

  end

This code is used in section 106.

109. ⟨Read ligature/kern list 109⟩ ≡

  begin *lk_step_ended* ← *false*;

  while *level* = 1 **do**

    begin while *cur_char* = "␣" **do** *get_next*;

    if *cur_char* = "(" **then** ⟨Read a ligature/kern command 110⟩

    else if *cur_char* = ")" **then** *skip_to_end_of_item*

      else *junk_error*;

    end;

  finish_inner_property_list;

  end

This code is used in section 180.

110. ⟨Read a ligature/kern command 110⟩ ≡

  begin *get_name*;

  if *cur_code* = *comment_code* **then** *skip_to_end_of_item*

  else if *cur_code* < *label_code* **then**

      flush_error(ˊThis␣property␣name␣doesnˊˊt␣belong␣in␣a␣LIGTABLE␣listˊ)

    else begin case *cur_code* **of**

      label_code: ⟨Read a label step 112⟩;

      stop_code: ⟨Read a stop step 114⟩;

      skip_code: ⟨Read a skip step 115⟩;

      krn_code: ⟨Read a kerning step 117⟩;

      lig_code, *lig_code* + 1, *lig_code* + 2, *lig_code* + 3, *lig_code* + 5, *lig_code* + 6, *lig_code* + 7, *lig_code* + 11:

          ⟨Read a ligature step 116⟩;

      end;   {there are no other cases ≥ *label_code*}

      finish_the_property;

      end;

  end

This code is used in section 109.

111.   When a character is about to be tagged, we call the following procedure so that an error message is given in case of multiple tags.

procedure $check\_tag(c : byte)$;   { print error if c already tagged }
  begin case $char\_tag[c]$ **of**
  no_tag: $do\_nothing$;
  lig_tag: $err\_print(´This⎵character⎵already⎵appeared⎵in⎵a⎵LIGTABLE⎵LABEL´)$;
  $list\_tag$: $err\_print(´This⎵character⎵already⎵has⎵a⎵NEXTLARGER⎵spec´)$;
  ext_tag: $err\_print(´This⎵character⎵already⎵has⎵a⎵VARCHAR⎵spec´)$;
  end;
  end;

112.   ⟨ Read a label step 112 ⟩ ≡
  begin while $cur_char = $ "⎵" **do** get_next;
  if $cur_char = $ "B" **then**
    begin $bchar\_label \leftarrow nl$; $skip\_to\_paren$;   { LABEL BOUNDARYCHAR }
    end
  else begin $backup$; $c \leftarrow get\_byte$; $check\_tag(c)$; $char\_tag[c] \leftarrow lig\_tag$; $char\_remainder[c] \leftarrow nl$;
    end;
  if $min\_nl \leq nl$ **then** $min\_nl \leftarrow nl + 1$;
  $lk\_step\_ended \leftarrow false$;
  end

This code is used in section 110.

113.   **define** $stop\_flag = 128$ { value indicating 'STOP' in a lig/kern program }
  define $kern\_flag = 128$ { op code for a kern step }

⟨ Globals in the outer block 5 ⟩ +≡
lk_step_ended: $boolean$;   { was the last LIGTABLE property LIG or KRN? }
krn_ptr: $0 .. max\_kerns$;   { an index into $kern$ }

114.   ⟨ Read a stop step 114 ⟩ ≡
  if $\neg lk\_step\_ended$ **then** $err\_print(´STOP⎵must⎵follow⎵LIG⎵or⎵KRN´)$
  else begin $lig\_kern[nl - 1].b0 \leftarrow stop\_flag$; $lk\_step\_ended \leftarrow false$;
    end

This code is used in section 110.

115.   ⟨ Read a skip step 115 ⟩ ≡
  if $\neg lk\_step\_ended$ **then** $err\_print(´SKIP⎵must⎵follow⎵LIG⎵or⎵KRN´)$
  else begin $c \leftarrow get\_byte$;
    if $c \geq 128$ **then** $err\_print(´Maximum⎵SKIP⎵amount⎵is⎵127´)$
    else if $nl + c \geq max\_lig\_steps$ **then** $err\_print(´Sorry,⎵LIGTABLE⎵too⎵long⎵for⎵me⎵to⎵handle´)$
      else begin $lig\_kern[nl - 1].b0 \leftarrow c$;
        if $min\_nl \leq nl + c$ **then** $min\_nl \leftarrow nl + c + 1$;
        end;
    $lk\_step\_ended \leftarrow false$;
    end

This code is used in section 110.

116. ⟨Read a ligature step 116⟩ ≡
  begin $lig\_kern[nl].b0 \leftarrow 0$; $lig\_kern[nl].b2 \leftarrow cur\_code - lig\_code$; $lig\_kern[nl].b1 \leftarrow get\_byte$;
  $lig\_kern[nl].b3 \leftarrow get\_byte$;
  if $nl \geq max\_lig\_steps - 1$ **then** $err\_print(´Sorry,_⊔LIGTABLE_⊔too_⊔long_⊔for_⊔me_⊔to_⊔handle´)$
  else $incr(nl)$;
  $lk\_step\_ended \leftarrow true$;
  end

This code is used in section 110.

117. ⟨Read a kerning step 117⟩ ≡
  begin $lig\_kern[nl].b0 \leftarrow 0$; $lig\_kern[nl].b1 \leftarrow get\_byte$; $kern[nk] \leftarrow get\_fix$; $krn\_ptr \leftarrow 0$;
  while $kern[krn\_ptr] \neq kern[nk]$ **do** $incr(krn\_ptr)$;
  if $krn\_ptr = nk$ **then**
    begin if $nk < max\_kerns$ **then** $incr(nk)$
    else begin $err\_print(´Sorry,_⊔too_⊔many_⊔different_⊔kerns_⊔for_⊔me_⊔to_⊔handle´)$; $decr(krn\_ptr)$;
      end;
    end;
  $lig\_kern[nl].b2 \leftarrow kern\_flag + (krn\_ptr \textbf{ div } 256)$; $lig\_kern[nl].b3 \leftarrow krn\_ptr \textbf{ mod } 256$;
  if $nl \geq max\_lig\_steps - 1$ **then** $err\_print(´Sorry,_⊔LIGTABLE_⊔too_⊔long_⊔for_⊔me_⊔to_⊔handle´)$
  else $incr(nl)$;
  $lk\_step\_ended \leftarrow true$;
  end

This code is used in section 110.

118. Finally we come to the part of VPtoVF's input mechanism that is used most, the processing of individual character data.

⟨Read character info list 118⟩ ≡
  begin $c \leftarrow get\_byte$; { read the character code that is being specified }
  ⟨Print c in octal notation 137⟩;
  while $level = 1$ **do**
    begin while $cur\_char = "_⊔"$ **do** get_next;
    if $cur\_char = "("$ **then** ⟨Read a character property 119⟩
    else if $cur\_char = ")"$ **then** $skip\_to\_end\_of\_item$
      else $junk\_error$;
    end;
  if $char\_wd[c] = 0$ **then** $char\_wd[c] \leftarrow sort\_in(width, 0)$;   { legitimatize c }
  $finish\_inner\_property\_list$;
  end

This code is used in section 180.

119. ⟨Read a character property 119⟩ ≡
  begin *get_name*;
  if *cur_code* = *comment_code* **then** *skip_to_end_of_item*
  else if (*cur_code* < *char_wd_code*) ∨ (*cur_code* > *var_char_code*) **then**
    flush_error(´This␣property␣name␣doesn´´t␣belong␣in␣a␣CHARACTER␣list´)
   else begin case *cur_code* **of**
    char_wd_code: *char_wd*[*c*] ← *sort_in*(*width*, *get_fix*);
    char_ht_code: *char_ht*[*c*] ← *sort_in*(*height*, *get_fix*);
    char_dp_code: *char_dp*[*c*] ← *sort_in*(*depth*, *get_fix*);
    char_ic_code: *char_ic*[*c*] ← *sort_in*(*italic*, *get_fix*);
    next_larger_code: **begin** *check_tag*(*c*); *char_tag*[*c*] ← *list_tag*; *char_remainder*[*c*] ← *get_byte*;
      end;
    map_code: *read_packet*(*c*);
    var_char_code: ⟨Read an extensible recipe for *c* 120⟩;
    end;
    finish_the_property;
    end;
  end

This code is used in section 118.

120. ⟨Read an extensible recipe for *c* 120⟩ ≡
  begin if *ne* = 256 **then** *err_print*(´At␣most␣256␣VARCHAR␣specs␣are␣allowed´)
  else begin *check_tag*(*c*); *char_tag*[*c*] ← *ext_tag*; *char_remainder*[*c*] ← *ne*;
   exten[*ne*] ← *zero_bytes*;
   while *level* = 2 **do**
    begin while *cur_char* = "␣" **do** *get_next*;
    if *cur_char* = "(" **then** ⟨Read an extensible piece 121⟩
    else if *cur_char* = ")" **then** *skip_to_end_of_item*
      else *junk_error*;
    end;
   incr(*ne*); *finish_inner_property_list*;
    end;
  end

This code is used in section 119.

121. ⟨Read an extensible piece 121⟩ ≡
  begin *get_name*;
  if *cur_code* = *comment_code* **then** *skip_to_end_of_item*
  else if (*cur_code* < *var_char_code* + 1) ∨ (*cur_code* > *var_char_code* + 4) **then**
    flush_error(´This␣property␣name␣doesn´´t␣belong␣in␣a␣VARCHAR␣list´)
   else begin case *cur_code* − (*var_char_code* + 1) **of**
    0: *exten*[*ne*].*b0* ← *get_byte*;
    1: *exten*[*ne*].*b1* ← *get_byte*;
    2: *exten*[*ne*].*b2* ← *get_byte*;
    3: *exten*[*ne*].*b3* ← *get_byte*;
    end;
    finish_the_property;
    end;
  end

This code is used in section 120.

122. Assembling the mappings.   Each MAP property is a sequence of DVI instructions, for which we
need to know some of the opcodes.

> **define** $set\_char\_0 = 0$ { DVI command to typeset character 0 and move right }
> **define** $set1 = 128$ { typeset a character and move right }
> **define** $set\_rule = 132$ { typeset a rule and move right }
> **define** $push = 141$ { save the current positions }
> **define** $pop = 142$ { restore previous positions }
> **define** $right1 = 143$ { move right }
> **define** $w0 = 147$ { move right by w }
> **define** $w1 = 148$ { move right and set w }
> **define** $x0 = 152$ { move right by x }
> **define** $x1 = 153$ { move right and set x }
> **define** $down1 = 157$ { move down }
> **define** $y0 = 161$ { move down by y }
> **define** $y1 = 162$ { move down and set y }
> **define** $z0 = 166$ { move down by z }
> **define** $z1 = 167$ { move down and set z }
> **define** $fnt\_num\_0 = 171$ { set current font to 0 }
> **define** $fnt1 = 235$ { set current font }
> **define** $xxx1 = 239$ { extension to DVI primitives }
> **define** $xxx4 = 242$ { potentially long extension to DVI primitives }
> **define** $fnt\_def1 = 243$ { define the meaning of a font number }
> **define** $pre = 247$ { preamble }
> **define** $post = 248$ { postamble beginning }

123.   We keep stacks of movement values, in order to optimize the DVI code in simple cases.

⟨ Globals in the outer block 5 ⟩ +≡
$hstack$: **array** $[0 .. max\_stack]$ **of** $0 .. 2$;   { number of known horizontal movements }
$vstack$: **array** $[0 .. max\_stack]$ **of** $0 .. 2$;   { number of known vertical movements }
$wstack, xstack, ystack, zstack$: **array** $[0 .. max\_stack]$ **of** fix_word;
$stack\_ptr$: $0 .. max\_stack$;

124.   The packet is built by straightforward assembly of DVI instructions.

⟨ Declare the vf_fix procedure 128 ⟩

procedure $read\_packet(c : byte)$;

  var cc: $byte$;   { character being typeset }

    x: fix_word;   { movement }

    h, v: $0 . . 2$;   { top of $hstack$ and $vstack$ }

    $special\_start$: $0 . . vf\_size$;   { location of $xxx1$ command }

    k: $0 . . vf\_size$;   { loop index }

  begin $packet\_start[c] \leftarrow vf\_ptr$; $stack\_ptr \leftarrow 0$; $h \leftarrow 0$; $v \leftarrow 0$; $cur\_font \leftarrow 0$;

  while $level = 2$ **do**

    begin while $cur_char = $ "␣" **do** get_next;

    if $cur_char = $ "(" **then** ⟨ Read and assemble a list of DVI commands 125 ⟩

    else if $cur_char = $ ")" **then** $skip\_to\_end\_of\_item$

      else $junk\_error$;

    end;

  while $stack\_ptr > 0$ **do**

    begin $err\_print(\text{´Missing␣POP␣supplied´})$; $vf\_store(pop)$; $decr(stack\_ptr)$;

    end;

  $packet\_length[c] \leftarrow vf\_ptr - packet\_start[c]$; $finish\_inner\_property\_list$;

  end;

125.   ⟨ Read and assemble a list of DVI commands 125 ⟩ ≡

  begin get_name;

  if $cur\_code = comment\_code$ **then** $skip\_to\_end\_of\_item$

  else if $(cur\_code < select\_font\_code) \vee (cur\_code > special\_hex\_code)$ **then**

    $flush\_error(\text{´This␣property␣name␣doesn´´t␣belong␣in␣a␣MAP␣list´})$

    else begin case cur_code **of**

      $select\_font\_code$: ⟨ Assemble a font selection 126 ⟩;

      set_char_code: ⟨ Assemble a typesetting instruction 127 ⟩;

      set_rule_code: ⟨ Assemble a rulesetting instruction 129 ⟩;

      $move\_right\_code, move\_right\_code + 1$: ⟨ Assemble a horizontal movement 130 ⟩;

      $move\_down\_code, move\_down\_code + 1$: ⟨ Assemble a vertical movement 131 ⟩;

      $push\_code$: ⟨ Assemble a stack push 132 ⟩;

      pop_code: ⟨ Assemble a stack pop 133 ⟩;

      $special\_code, special\_hex\_code$: ⟨ Assemble a special command 134 ⟩;

      end;

      $finish\_the\_property$;

      end;

  end

This code is used in section 124.

126.   ⟨ Assemble a font selection 126 ⟩ ≡

  begin get_four_bytes; $font\_number[font\_ptr] \leftarrow cur\_bytes$; $cur\_font \leftarrow 0$;

  while $numbers\_differ$ **do** $incr(cur\_font)$;

  if $cur\_font = font\_ptr$ **then** $err\_print(\text{´Undefined␣MAPFONT␣cannot␣be␣selected´})$

  else if $cur\_font < 64$ **then** $vf\_store(fnt\_num\_0 + cur\_font)$

    else begin $vf\_store(fnt1)$; $vf\_store(cur\_font)$;

      end;

  end

This code is used in section 125.

127. ⟨Assemble a typesetting instruction 127⟩ ≡
  if $cur\_font = font\_ptr$ **then** $err\_print($ ´Character␣cannot␣be␣typeset␣in␣undefined␣font´ $)$
  else begin $cc \leftarrow get\_byte$;
    if $cc \geq 128$ **then** $vf\_store(set1)$;
    $vf\_store(cc)$;
    end

This code is used in section 125.

128. Here's a procedure that converts a *fix_word* to a sequence of DVI bytes.

⟨Declare the *vf_fix* procedure 128⟩ ≡
procedure $vf\_fix(opcode : byte; \ x : fix\_word)$;
  var *negative*: *boolean*; k: $0 \mathrel{..} 4$; {number of bytes to typeset}
    t: *integer*; {threshold}
  begin $frozen\_du \leftarrow true$;
  if $design\_units \neq unity$ **then** $x \leftarrow round((x/design\_units) * 1048576.0)$;
  if $x \geq 0$ **then** $negative \leftarrow false$
  else begin $negative \leftarrow true$; $x \leftarrow -1 - x$; **end**;
  if $opcode = 0$ **then**
    begin $k \leftarrow 4$; $t \leftarrow$ ´100000000; **end**
  else begin $t \leftarrow 127$; $k \leftarrow 1$;
    while $x > t$ **do**
      begin $t \leftarrow 256 * t + 255$; $incr(k)$;
      end;
    $vf\_store(opcode + k - 1)$; $t \leftarrow t$ **div** $128 + 1$;
    end;
  repeat if *negative* **then**
      begin $vf\_store(255 - (x \mathbf{\ div\ } t))$; $negative \leftarrow false$; $x \leftarrow (x \mathbf{\ div\ } t) * t + t - 1 - x$;
      end
    else $vf\_store((x \mathbf{\ div\ } t) \mathbf{\ mod\ } 256)$;
    $decr(k)$; $t \leftarrow t$ **div** 256;
  until $k = 0$;
  end;

This code is used in section 124.

129. ⟨Assemble a rulesetting instruction 129⟩ ≡
  begin $vf\_store(set\_rule)$; $vf\_fix(0, get\_fix)$; $vf\_fix(0, get\_fix)$;
  end

This code is used in section 125.

130. ⟨Assemble a horizontal movement 130⟩ ≡
  begin if $cur\_code = move\_right\_code$ **then** $x \leftarrow get\_fix$ **else** $x \leftarrow -get\_fix$;
  if $h = 0$ **then**
    begin $wstack[stack\_ptr] \leftarrow x$; $h \leftarrow 1$; $vf\_fix(w1, x)$; **end**
  else if $x = wstack[stack\_ptr]$ **then** $vf\_store(w0)$
    else if $h = 1$ **then**
        begin $xstack[stack\_ptr] \leftarrow x$; $h \leftarrow 2$; $vf\_fix(x1, x)$; **end**
      else if $x = xstack[stack\_ptr]$ **then** $vf\_store(x0)$
        else $vf\_fix(right1, x)$;
  end

This code is used in section 125.

131. ⟨Assemble a vertical movement 131⟩ ≡
  begin if $cur\_code = move\_down\_code$ **then** $x \leftarrow get\_fix$ **else** $x \leftarrow -get\_fix$;
  if $v = 0$ **then**
     begin $ystack[stack\_ptr] \leftarrow x$; $v \leftarrow 1$; $vf\_fix(y1, x)$; **end**
  else if $x = ystack[stack\_ptr]$ **then** $vf\_store(y0)$
     else if $v = 1$ **then**
           begin $zstack[stack\_ptr] \leftarrow x$; $v \leftarrow 2$; $vf\_fix(z1, x)$; **end**
        else if $x = zstack[stack\_ptr]$ **then** $vf\_store(z0)$
           else $vf\_fix(down1, x)$;
  end
This code is used in section 125.

132. ⟨Assemble a stack push 132⟩ ≡
  if $stack\_ptr = max\_stack$ **then**   { too pushy }
     $err\_print(\text{´Don´´t}_\sqcup\text{push}_\sqcup\text{so}_\sqcup\text{much---stack}_\sqcup\text{is}_\sqcup\text{full!´})$
  else begin $vf\_store(push)$; $hstack[stack\_ptr] \leftarrow h$; $vstack[stack\_ptr] \leftarrow v$; $incr(stack\_ptr)$; $h \leftarrow 0$; $v \leftarrow 0$;
     end
This code is used in section 125.

133. ⟨Assemble a stack pop 133⟩ ≡
  if $stack\_ptr = 0$ **then** $err\_print(\text{´Empty}_\sqcup\text{stack}_\sqcup\text{cannot}_\sqcup\text{be}_\sqcup\text{popped´})$
  else begin $vf\_store(pop)$; $decr(stack\_ptr)$; $h \leftarrow hstack[stack\_ptr]$; $v \leftarrow vstack[stack\_ptr]$;
     end
This code is used in section 125.

134. ⟨Assemble a special command 134⟩ ≡
  begin $vf\_store(xxx1)$; $vf\_store(0)$;   { dummy length }
  $special\_start \leftarrow vf\_ptr$;
  if $cur\_code = special\_code$ **then** $copy\_to\_end\_of\_item$
  else begin repeat $x \leftarrow get\_hex$;
      if $cur\_char > \text{")"}$ **then** $vf\_store(x * 16 + get\_hex)$;
     until $cur\_char \leq \text{")"}$;
     end;
  if $vf\_ptr - special\_start > 255$ **then** ⟨Convert $xxx1$ command to $xxx4$ 135⟩
  else $vf[special\_start - 1] \leftarrow vf\_ptr - special\_start$;
  end
This code is used in section 125.

135. ⟨Convert $xxx1$ command to $xxx4$ 135⟩ ≡
  if $vf\_ptr + 3 > vf\_size$ **then**
     begin $err\_print(\text{´Special}_\sqcup\text{command}_\sqcup\text{being}_\sqcup\text{clipped---no}_\sqcup\text{room}_\sqcup\text{left!´})$;
     $vf\_ptr \leftarrow special\_start + 255$; $vf[special\_start - 1] \leftarrow 255$;
     end
  else begin for $k \leftarrow vf\_ptr$ **downto** $special\_start$ **do** $vf[k + 3] \leftarrow vf[k]$;
     $x \leftarrow vf\_ptr - special\_start$; $vf\_ptr \leftarrow vf\_ptr + 3$; $vf[special\_start - 2] \leftarrow xxx4$;
     $vf[special\_start - 1] \leftarrow x$ **div** $´100000000$; $vf[special\_start] \leftarrow (x$ **div** $´200000)$ **mod** 256;
     $vf[special\_start + 1] \leftarrow (x$ **div** $´400)$ **mod** 256; $vf[special\_start + 2] \leftarrow x$ **mod** 256;
     end
This code is used in section 134.

136.   The input routine is now complete except for the following code, which prints a progress report as the file is being read.

procedure $print\_octal(c : byte)$;   { prints three octal digits }
   begin $print(\verb|````|, (c \textbf{ div } 64) : 1, ((c \textbf{ div } 8) \textbf{ mod } 8) : 1, (c \textbf{ mod } 8) : 1)$;
   end;

137.   ⟨ Print c in octal notation 137 ⟩ ≡
   begin if $chars\_on\_line = 8$ **then**
      begin $print\_ln(\verb|´␣´|)$; $chars\_on\_line \leftarrow 1$;
      end
   else begin if $chars\_on\_line > 0$ **then** $print(\verb|´␣´|)$;
      $incr(chars\_on\_line)$;
      end;
   $print\_octal(c)$;   { progress report }
   end

This code is used in section 118.

138. The checking and massaging phase.   Once the whole VPL file has been read in, we must check it
for consistency and correct any errors. This process consists mainly of running through the characters that
exist and seeing if they refer to characters that don't exist. We also compute the true value of *seven_unsafe*;
we make sure that the charlists and ligature programs contain no loops; and we shorten the lists of widths,
heights, depths, and italic corrections, if necessary, to keep from exceeding the required maximum sizes.

⟨ Globals in the outer block 5 ⟩ +≡
seven_unsafe : *boolean*;   { do seven-bit characters generate eight-bit ones? }

139.   ⟨ Correct and check the information 139 ⟩ ≡
  if *nl* > 0 **then** ⟨ Make sure the ligature/kerning program ends appropriately 145 ⟩;
  seven_unsafe ← *false*;
  for *c* ← 0 **to** 255 **do**
    if *char_wd*[*c*] ≠ 0 **then** ⟨ For all characters *g* generated by *c*, make sure that *char_wd*[*g*] is nonzero,
          and set *seven_unsafe* if *c* < 128 ≤ *g* 140 ⟩;
  if *bchar_label* < ´77777 **then**
    begin *c* ← 256; ⟨ Check ligature program of *c* 149 ⟩;
    end;
  if *seven_bit_safe_flag* ∧ *seven_unsafe* **then** *print_ln*(´The␣font␣is␣not␣really␣seven-bit-safe!´);
  ⟨ Check for infinite ligature loops 154 ⟩;
  ⟨ Doublecheck the lig/kern commands and the extensible recipes 155 ⟩;
  for *c* ← 0 **to** 255 **do** ⟨ Make sure that *c* is not the largest element of a charlist cycle 142 ⟩;
  ⟨ Put the width, height, depth, and italic lists into final form 144 ⟩
This code is used in section 180.

140.   The checking that we need in several places is accomplished by three macros that are only slightly
tricky.
  define *existence_tail*(#) ≡
          begin *char_wd*[*g*] ← *sort_in*(*width*, 0); *print*(#, ´␣´); *print_octal*(*c*);
          print_ln(´␣had␣no␣CHARACTER␣spec.´);
          end;
        end
  define *check_existence_and_safety*(#) ≡
        begin *g* ← #;
        if (*g* ≥ 128) ∧ (*c* < 128) **then** *seven_unsafe* ← *true*;
        if *char_wd*[*g*] = 0 **then** *existence_tail*
  define *check_existence*(#) ≡
        begin *g* ← #;
        if *char_wd*[*g*] = 0 **then** *existence_tail*
⟨ For all characters *g* generated by *c*, make sure that *char_wd*[*g*] is nonzero, and set *seven_unsafe* if
      c < 128 ≤ *g* 140 ⟩ ≡
  case *char_tag*[*c*] **of**
  no_tag: *do_nothing*;
  lig_tag: ⟨ Check ligature program of *c* 149 ⟩;
  list_tag: *check_existence_and_safety*(*char_remainder*[*c*])(´The␣character␣NEXTLARGER␣than´);
  ext_tag: ⟨ Check the pieces of *exten*[*c*] 141 ⟩;
    end
This code is used in section 139.

141. ⟨Check the pieces of *exten*[*c*] 141⟩ ≡
  begin if *exten*[*char_remainder*[*c*]].*b0* > 0 **then**
    check_existence_and_safety(*exten*[*char_remainder*[*c*]].*b0*)(´TOP␣piece␣of␣character´);
  if *exten*[*char_remainder*[*c*]].*b1* > 0 **then**
    check_existence_and_safety(*exten*[*char_remainder*[*c*]].*b1*)(´MID␣piece␣of␣character´);
  if *exten*[*char_remainder*[*c*]].*b2* > 0 **then**
    check_existence_and_safety(*exten*[*char_remainder*[*c*]].*b2*)(´BOT␣piece␣of␣character´);
  check_existence_and_safety(*exten*[*char_remainder*[*c*]].*b3*)(´REP␣piece␣of␣character´);
  end

This code is used in section 140.

142. ⟨Make sure that *c* is not the largest element of a charlist cycle 142⟩ ≡
  if *char_tag*[*c*] = *list_tag* **then**
    begin *g* ← *char_remainder*[*c*];
    while (*g* < *c*) ∧ (*char_tag*[*g*] = *list_tag*) **do** *g* ← *char_remainder*[*g*];
    if *g* = *c* **then**
      begin *char_tag*[*c*] ← *no_tag*;
      print(´A␣cycle␣of␣NEXTLARGER␣characters␣has␣been␣broken␣at␣´); *print_octal*(*c*);
      print_ln(´.´);
      end;
    end

This code is used in section 139.

143. ⟨Globals in the outer block 5⟩ +≡
delta: *fix_word*; {size of the intervals needed for rounding}

144.   **define** *round_message*(#) ≡
        if *delta* > 0 **then**
          print_ln(´I␣had␣to␣round␣some␣´, #, ´s␣by␣´, (((*delta*+1)**div**2)/´4000000) : 1 : 7, ´␣units.´)
⟨Put the width, height, depth, and italic lists into final form 144⟩ ≡
  delta ← *shorten*(*width*, 255); *set_indices*(*width*, *delta*); *round_message*(´width´);
  delta ← *shorten*(*height*, 15); *set_indices*(*height*, *delta*); *round_message*(´height´);
  delta ← *shorten*(*depth*, 15); *set_indices*(*depth*, *delta*); *round_message*(´depth´);
  delta ← *shorten*(*italic*, 63); *set_indices*(*italic*, *delta*); *round_message*(´italic␣correction´);
This code is used in section 139.

145.   **define** *clear_lig_kern_entry* ≡   {make an unconditional STOP}
        lig_kern[*nl*].*b0* ← 255; *lig_kern*[*nl*].*b1* ← 0; *lig_kern*[*nl*].*b2* ← 0; *lig_kern*[*nl*].*b3* ← 0
⟨Make sure the ligature/kerning program ends appropriately 145⟩ ≡
  begin if *bchar_label* < ´77777 **then**   {make room for it}
    begin *clear_lig_kern_entry*; *incr*(*nl*);
    end;   {*bchar_label* will be stored later}
  while *min_nl* > *nl* **do**
    begin *clear_lig_kern_entry*; *incr*(*nl*);
    end;
  if *lig_kern*[*nl* − 1].*b0* = 0 **then** *lig_kern*[*nl* − 1].*b0* ← *stop_flag*;
  end

This code is used in section 139.

146.   It's not trivial to check for infinite loops generated by repeated insertion of ligature characters. But fortunately there is a nice algorithm for such testing, copied here from the program `TFtoPL` where it is explained further.

   define $simple = 0$ $\{ f(x, y) = z \}$
   define $left\_z = 1$ $\{ f(x, y) = f(z, y) \}$
   define $right\_z = 2$ $\{ f(x, y) = f(x, z) \}$
   define $both\_z = 3$ $\{ f(x, y) = f(f(x, z), y) \}$
   define $pending = 4$ $\{ f(x, y)$ is being evaluated $\}$

147.   ⟨Globals in the outer block 5⟩ +≡
lig_ptr: $0 \mathrel{.\,.} max\_lig\_steps$;   { an index into lig_kern }
$hash$: **array** $[0 \mathrel{.\,.} hash\_size]$ **of** $0 \mathrel{.\,.} 66048$; $\{ 256x + y + 1$ for $x \leq 257$ and $y \leq 255 \}$
$class$: **array** $[0 \mathrel{.\,.} hash\_size]$ **of** $simple \mathrel{.\,.} pending$;
lig_z: **array** $[0 \mathrel{.\,.} hash\_size]$ **of** $0 \mathrel{.\,.} 257$;
$hash\_ptr$: $0 \mathrel{.\,.} hash\_size$;   { the number of nonzero entries in $hash$ }
$hash\_list$: **array** $[0 \mathrel{.\,.} hash\_size]$ **of** $0 \mathrel{.\,.} hash\_size$;   { list of those nonzero entries }
h, hh: $0 \mathrel{.\,.} hash\_size$;   { indices into the hash table }
tt: $indx$;   { temporary register }
x_lig_cycle, y_lig_cycle: $0 \mathrel{.\,.} 256$;   { problematic ligature pair }

148.   ⟨Set initial values 6⟩ +≡
  $hash\_ptr \leftarrow 0$; $y\_lig\_cycle \leftarrow 256$;
  for $k \leftarrow 0$ **to** $hash\_size$ **do** $hash[k] \leftarrow 0$;

149.   **define** $lig\_exam \equiv lig\_kern[lig\_ptr].b1$
  define $lig\_gen \equiv lig\_kern[lig\_ptr].b3$
⟨Check ligature program of c 149⟩ ≡
  begin $lig\_ptr \leftarrow char\_remainder[c]$;
  repeat if $hash\_input(lig\_ptr, c)$ **then**
     begin if $lig\_kern[lig\_ptr].b2 < kern\_flag$ **then**
       begin if $lig\_exam \neq bchar$ **then** $check\_existence(lig\_exam)($´LIG␣character␣examined␣by´$)$;
       $check\_existence(lig\_gen)($´LIG␣character␣generated␣by´$)$;
       if $lig\_gen \geq 128$ **then**
         if $(c < 128) \vee (c = 256)$ **then**
           if $(lig\_exam < 128) \vee (lig\_exam = bchar)$ **then** $seven\_unsafe \leftarrow true$;
       end
     else if $lig\_exam \neq bchar$ **then** $check\_existence(lig\_exam)($´KRN␣character␣examined␣by´$)$;
     end;
   if $lig\_kern[lig\_ptr].b0 \geq stop\_flag$ **then** $lig\_ptr \leftarrow nl$
   else $lig\_ptr \leftarrow lig\_ptr + 1 + lig\_kern[lig\_ptr].b0$;
  until $lig\_ptr \geq nl$;
  end
This code is used in sections 139 and 140.

150.   The *hash_input* procedure is copied from `TFtoPL`, but it is made into a boolean function that returns *false* if the ligature command was masked by a previous one.

function *hash_input*(p, c : *indx*): *boolean*;
        { enter data for character c and command in location p, unless it isn't new }
  label 30;   { go here for a quick exit }
  var *cc*: *simple* .. *both_z*;   { class of data being entered }
    zz: 0 .. 255;   { function value or ligature character being entered }
    y: 0 .. 255;   { the character after the cursor }
    key: *integer*;   { value to be stored in *hash* }
    t: *integer*;   { temporary register for swapping }
  begin if *hash_ptr* = *hash_size* **then**
    begin *hash_input* ← *false*; **goto** 30; **end**;
  ⟨ Compute the command parameters y, *cc*, and *zz* 151 ⟩;
  key ← 256 ∗ c + y + 1; h ← (1009 ∗ *key*) **mod** *hash_size*;
  while *hash*[h] > 0 **do**
    begin if *hash*[h] ≤ *key* **then**
      begin if *hash*[h] = *key* **then**
        begin *hash_input* ← *false*; **goto** 30;   { unused ligature command }
        end;
      t ← *hash*[h]; *hash*[h] ← *key*; *key* ← t;   { do ordered-hash-table insertion }
      t ← *class*[h]; *class*[h] ← *cc*; *cc* ← t;   { namely, do a swap }
      t ← *lig_z*[h]; *lig_z*[h] ← *zz*; *zz* ← t;
      end;
    if h > 0 **then** *decr*(h) **else** h ← *hash_size*;
    end;
  hash[h] ← *key*; *class*[h] ← *cc*; *lig_z*[h] ← *zz*; *incr*(*hash_ptr*); *hash_list*[*hash_ptr*] ← h;
  hash_input ← *true*;
30: **end**;

151.   ⟨ Compute the command parameters y, *cc*, and *zz* 151 ⟩ ≡
  y ← *lig_kern*[p].*b1*; t ← *lig_kern*[p].*b2*; *cc* ← *simple*; *zz* ← *lig_kern*[p].*b3*;
  if t ≥ *kern_flag* **then** *zz* ← y
  else begin case t **of**
    0, 6: *do_nothing*;   { `LIG`,`/LIG>` }
    5, 11: *zz* ← y;   { `LIG/>`, `/LIG/>>` }
    1, 7: *cc* ← *left_z*;   { `LIG/`, `/LIG/>` }
    2: *cc* ← *right_z*;   { `/LIG` }
    3: *cc* ← *both_z*;   { `/LIG/` }
    end;   { there are no other cases }
    end
This code is used in section 150.

152.   (More good stuff from TFtoPL.)

function $f(h, x, y : indx)$: $indx$; $forward$;   { compute f for arguments known to be in $hash[h]$ }
function $eval(x, y : indx)$: $indx$;   { compute $f(x, y)$ with hashtable lookup }
  var key: $integer$;   { value sought in hash table }
  begin $key \leftarrow 256 * x + y + 1$; $h \leftarrow (1009 * key)$ **mod** $hash\_size$;
  while $hash[h] > key$ **do**
    if $h > 0$ **then** $decr(h)$ **else** $h \leftarrow hash\_size$;
  if $hash[h] < key$ **then** $eval \leftarrow y$ { not in ordered hash table }
  else $eval \leftarrow f(h, x, y)$;
  end;

153.   Pascal's beastly convention for *forward* declarations prevents us from saying **function** $f(h, x, y : indx)$: $indx$ here.

function f;
  begin case $class[h]$ **of**
  $simple$: $do\_nothing$;
  $left\_z$: **begin** $class[h] \leftarrow pending$; $lig\_z[h] \leftarrow eval(lig\_z[h], y)$; $class[h] \leftarrow simple$;
    end;
  $right\_z$: **begin** $class[h] \leftarrow pending$; $lig\_z[h] \leftarrow eval(x, lig\_z[h])$; $class[h] \leftarrow simple$;
    end;
  $both\_z$: **begin** $class[h] \leftarrow pending$; $lig\_z[h] \leftarrow eval(eval(x, lig\_z[h]), y)$; $class[h] \leftarrow simple$;
    end;
  $pending$: **begin** $x\_lig\_cycle \leftarrow x$; $y\_lig\_cycle \leftarrow y$; $lig\_z[h] \leftarrow 257$; $class[h] \leftarrow simple$;
    end;   { the value 257 will break all cycles, since it's not in $hash$ }
  end;   { there are no other cases }
  $f \leftarrow lig\_z[h]$;
  end;

154.   ⟨ Check for infinite ligature loops 154 ⟩ ≡
  if $hash\_ptr < hash\_size$ **then**
    for $hh \leftarrow 1$ **to** $hash\_ptr$ **do**
      begin $tt \leftarrow hash\_list[hh]$;
      if $class[tt] > simple$ **then**   { make sure f is well defined }
        $tt \leftarrow f(tt, (hash[tt] - 1)$ **div** $256, (hash[tt] - 1)$ **mod** $256)$;
      end;
  if $(hash\_ptr = hash\_size) \vee (y\_lig\_cycle < 256)$ **then**
    begin if $hash\_ptr < hash\_size$ **then**
      begin $print(´Infinite_ligature_loop_starting_with_´)$;
      if $x\_lig\_cycle = 256$ **then** $print(´boundary´)$ **else** $print\_octal(x\_lig\_cycle)$;
      $print(´_and_´)$; $print\_octal(y\_lig\_cycle)$; $print\_ln(´!´)$;
      end
    else $print\_ln(´Sorry,_I_haven´´t_room_for_so_many_ligature/kern_pairs!´)$;
    $print\_ln(´All_ligatures_will_be_cleared.´)$;
    for $c \leftarrow 0$ **to** 255 **do**
      if $char\_tag[c] = lig\_tag$ **then**
        begin $char\_tag[c] \leftarrow no\_tag$; $char\_remainder[c] \leftarrow 0$;
        end;
    $nl \leftarrow 0$; $bchar \leftarrow 256$; $bchar\_label \leftarrow ´77777$;
    end

This code is used in section 139.

155.   The lig/kern program may still contain references to nonexistent characters, if parts of that program are never used. Similarly, there may be extensible characters that are never used, because they were overridden by `NEXTLARGER`, say. This would produce an invalid `TFM` file; so we must fix such errors.

define $double\_check\_tail(\#) \equiv$
        if $char\_wd[0] = 0$ **then** $char\_wd[0] \leftarrow sort\_in(width, 0)$;
        $print(\text{´Unused}_\sqcup\text{´}, \#, \text{´}_\sqcup\text{refers}_\sqcup\text{to}_\sqcup\text{nonexistent}_\sqcup\text{character}_\sqcup\text{´})$; $print\_octal(c)$; $print\_ln(\text{´!´})$;
        end ;
        end
define $double\_check\_lig(\#) \equiv$
     begin $c \leftarrow lig\_kern[lig\_ptr].\#$;
     if $char\_wd[c] = 0$ **then**
       if $c \neq bchar$ **then**
         begin $lig\_kern[lig\_ptr].\# \leftarrow 0$; $double\_check\_tail$
define $double\_check\_ext(\#) \equiv$
     begin $c \leftarrow exten[g].\#$;
     if $c > 0$ **then**
       if $char\_wd[c] = 0$ **then**
         begin $exten[g].\# \leftarrow 0$; $double\_check\_tail$
define $double\_check\_rep(\#) \equiv$
     begin $c \leftarrow exten[g].\#$;
     if $char\_wd[c] = 0$ **then**
       begin $exten[g].\# \leftarrow 0$; $double\_check\_tail$

⟨ Doublecheck the lig/kern commands and the extensible recipes 155 ⟩ $\equiv$
  if $nl > 0$ **then**
    for $lig\_ptr \leftarrow 0$ **to** $nl - 1$ **do**
      if $lig\_kern[lig\_ptr].b2 < kern\_flag$ **then**
        begin if $lig\_kern[lig\_ptr].b0 < 255$ **then**
          begin $double\_check\_lig(b1)(\text{´LIG}_\sqcup\text{step´})$; $double\_check\_lig(b3)(\text{´LIG}_\sqcup\text{step´})$;
          end;
        end
      else $double\_check\_lig(b1)(\text{´KRN}_\sqcup\text{step´})$;
  if $ne > 0$ **then**
    for $g \leftarrow 0$ **to** $ne - 1$ **do**
      begin $double\_check\_ext(b0)(\text{´VARCHAR}_\sqcup\text{TOP´})$; $double\_check\_ext(b1)(\text{´VARCHAR}_\sqcup\text{MID´})$;
      $double\_check\_ext(b2)(\text{´VARCHAR}_\sqcup\text{BOT´})$; $double\_check\_rep(b3)(\text{´VARCHAR}_\sqcup\text{REP´})$;
      end

This code is used in section 139.

156. The TFM output phase.   Now that we know how to get all of the font data correctly stored in
VPtoVF's memory, it only remains to write the answers out.

First of all, it is convenient to have an abbreviation for output to the TFM file:

> **define** $out(\#) \equiv write(tfm\_file, \#)$

157.   The general plan for producing TFM files is long but simple:

$\langle$ Do the TFM output 157 $\rangle \equiv$
$\quad \langle$ Compute the twelve subfile sizes 159 $\rangle$;
$\quad \langle$ Output the twelve subfile sizes 160 $\rangle$;
$\quad \langle$ Output the header block 162 $\rangle$;
$\quad \langle$ Output the character info 164 $\rangle$;
$\quad \langle$ Output the dimensions themselves 166 $\rangle$;
$\quad \langle$ Output the ligature/kern program 171 $\rangle$;
$\quad \langle$ Output the extensible character recipes 172 $\rangle$;
$\quad \langle$ Output the parameters 173 $\rangle$
This code is used in section 181.

158.   A TFM file begins with 12 numbers that tell how big its subfiles are. We already know most of these
numbers; for example, the number of distinct widths is $memory[width] + 1$, where the $+1$ accounts for the
zero width that is always supposed to be present. But we still should compute the beginning and ending
character codes (bc and ec), the number of header words (lh), and the total number of words in the TFM file
(lf).

$\langle$ Globals in the outer block 5 $\rangle$ $+\equiv$
bc: $byte$;   { the smallest character code in the font }
ec: $byte$;   { the largest character code in the font }
lh: $byte$;   { the number of words in the header block }
lf: $0 .. 32767$;   { the number of words in the entire TFM file }
not_found: $boolean$;   { has a font character been found? }
$temp\_width$: fix_word;   { width being used to compute a check sum }

159.   It might turn out that no characters exist at all. But VPtoVF keeps going and writes the TFM anyway.
In this case ec will be 0 and bc will be 1.

$\langle$ Compute the twelve subfile sizes 159 $\rangle \equiv$
$\quad lh \leftarrow header\_ptr$ **div** 4;
$\quad not\_found \leftarrow true$; $bc \leftarrow 0$;
$\quad$ **while** not_found **do**
$\quad\quad$ **if** $(char\_wd[bc] > 0) \vee (bc = 255)$ **then** $not\_found \leftarrow false$
$\quad\quad$ **else** $incr(bc)$;
$\quad not\_found \leftarrow true$; $ec \leftarrow 255$;
$\quad$ **while** not_found **do**
$\quad\quad$ **if** $(char\_wd[ec] > 0) \vee (ec = 0)$ **then** $not\_found \leftarrow false$
$\quad\quad$ **else** $decr(ec)$;
$\quad$ **if** $bc > ec$ **then** $bc \leftarrow 1$;
$\quad incr(memory[width])$; $incr(memory[height])$; $incr(memory[depth])$; $incr(memory[italic])$;
$\quad \langle$ Compute the ligature/kern program offset 168 $\rangle$;
$\quad lf \leftarrow 6 + lh + (ec - bc + 1) + memory[width] + memory[height] + memory[depth] + memory[italic] + nl +$
$\quad\quad lk\_offset + nk + ne + np$;
This code is used in section 157.

160.   **define** $out\_size(\#) \equiv out((\#) \textbf{ div } 256); \; out((\#) \textbf{ mod } 256)$

⟨ Output the twelve subfile sizes 160 ⟩ ≡
  $out\_size(lf); \; out\_size(lh); \; out\_size(bc); \; out\_size(ec); \; out\_size(memory[width]);$
  $out\_size(memory[height]); \; out\_size(memory[depth]); \; out\_size(memory[italic]); \; out\_size(nl + lk\_offset);$
  $out\_size(nk); \; out\_size(ne); \; out\_size(np);$

This code is used in section 157.

161.   The routines that follow need a few temporary variables of different types.

⟨ Globals in the outer block 5 ⟩ +≡
j: $0 .. max\_header\_bytes$;   { index into $header\_bytes$ }
p: $pointer$;   { index into $memory$ }
q: $width .. italic$;   { runs through the list heads for dimensions }
par_ptr: $0 .. max\_param\_words$;   { runs through the parameters }

162.   The header block follows the subfile sizes. The necessary information all appears in $header\_bytes$, except that the design size and the seven-bit-safe flag must still be set.

⟨ Output the header block 162 ⟩ ≡
  if ¬$check\_sum\_specified$ **then** ⟨ Compute the check sum 163 ⟩;
  $header\_bytes[design\_size\_loc] \leftarrow design\_size \textbf{ div } ´100000000;$ { this works since $design\_size > 0$ }
  $header\_bytes[design\_size\_loc + 1] \leftarrow (design\_size \textbf{ div } ´200000) \textbf{ mod } 256;$
  $header\_bytes[design\_size\_loc + 2] \leftarrow (design\_size \textbf{ div } 256) \textbf{ mod } 256;$
  $header\_bytes[design\_size\_loc + 3] \leftarrow design\_size \textbf{ mod } 256;$
  if ¬$seven\_unsafe$ **then** $header\_bytes[seven\_flag\_loc] \leftarrow 128;$
  for $j \leftarrow 0$ **to** $header\_ptr - 1$ **do** $out(header\_bytes[j]);$

This code is used in section 157.

163.   ⟨ Compute the check sum 163 ⟩ ≡
  begin $c0 \leftarrow bc; \; c1 \leftarrow ec; \; c2 \leftarrow bc; \; c3 \leftarrow ec;$
  for $c \leftarrow bc$ **to** ec **do**
    if $char\_wd[c] > 0$ **then**
      begin $temp\_width \leftarrow memory[char\_wd[c]];$
      if $design\_units \neq unity$ **then** $temp\_width \leftarrow round((temp\_width/design\_units) * 1048576.0);$
      $temp\_width \leftarrow temp\_width + (c + 4) * ´20000000;$ { this should be positive }
      $c0 \leftarrow (c0 + c0 + temp\_width) \textbf{ mod } 255; \; c1 \leftarrow (c1 + c1 + temp\_width) \textbf{ mod } 253;$
      $c2 \leftarrow (c2 + c2 + temp\_width) \textbf{ mod } 251; \; c3 \leftarrow (c3 + c3 + temp\_width) \textbf{ mod } 247;$
      end;
  $header\_bytes[check\_sum\_loc] \leftarrow c0; \; header\_bytes[check\_sum\_loc + 1] \leftarrow c1;$
  $header\_bytes[check\_sum\_loc + 2] \leftarrow c2; \; header\_bytes[check\_sum\_loc + 3] \leftarrow c3;$
  end

This code is used in section 162.

164.   The next block contains packed $char\_info$.

⟨ Output the character info 164 ⟩ ≡
  $index[0] \leftarrow 0;$
  for $c \leftarrow bc$ **to** ec **do**
    begin $out(index[char\_wd[c]]); \; out(index[char\_ht[c]] * 16 + index[char\_dp[c]]);$
    $out(index[char\_ic[c]] * 4 + char\_tag[c]); \; out(char\_remainder[c]);$
    end

This code is used in section 157.

165.   When a scaled quantity is output, we may need to divide it by *design_units*. The following subroutine takes care of this, using floating point arithmetic only if *design_units* ≠ 1.0.

procedure *out_scaled*(*x* : *fix_word*);   { outputs a scaled *fix_word* }
  var *n*: *byte*;   { the first byte after the sign }
    m: 0 . . 65535;   { the two least significant bytes }
  begin if *abs*(*x*/*design_units*) ≥ 16.0 **then**
    begin *print_ln*(´The␣relative␣dimension␣´, *x*/´4000000 : 1 : 3, ´␣is␣too␣large.´);
    print(´␣␣(Must␣be␣less␣than␣16*designsize´);
    if *design_units* ≠ *unity* **then** *print*(´␣=´, *design_units*/´200000 : 1 : 3, ´␣designunits´);
    print_ln(´)´); *x* ← 0;
    end;
  if *design_units* ≠ *unity* **then** *x* ← *round*((*x*/*design_units*) ∗ 1048576.0);
  if *x* < 0 **then**
    begin *out*(255); *x* ← *x* + ´100000000;
    if *x* ≤ 0 **then** *x* ← 1;
    end
  else begin *out*(0);
    if *x* ≥ ´100000000 **then** *x* ← ´77777777;
    end;
  n ← *x* **div** ´200000; *m* ← *x* **mod** ´200000; *out*(*n*); *out*(*m* **div** 256); *out*(*m* **mod** 256);
  end;

166.   We have output the packed indices for individual characters. The scaled widths, heights, depths, and italic corrections are next.

⟨ Output the dimensions themselves 166 ⟩ ≡
  for *q* ← *width* **to** *italic* **do**
    begin *out*(0); *out*(0); *out*(0); *out*(0);   { output the zero word }
    p ← *link*[*q*];   { head of list }
    while *p* > 0 **do**
      begin *out_scaled*(*memory*[*p*]); *p* ← *link*[*p*];
      end;
    end;

This code is used in section 157.

167.   One embarrassing problem remains: The ligature/kern program might be very long, but the starting addresses in *char_remainder* can be at most 255. Therefore we need to output some indirect address information; we want to compute *lk_offset* so that addition of *lk_offset* to all remainders makes all but *lk_offset* distinct remainders less than 256.

For this we need a sorted table of all relevant remainders.

⟨ Globals in the outer block 5 ⟩ +≡
label_table: **array** [0 . . 256] **of record** *rr*: −1 . . ´77777;   { sorted label values }
    cc: *byte*;   { associated characters }
    end;
label_ptr: 0 . . 256;   { index of highest entry in *label_table* }
sort_ptr: 0 . . 256;   { index into *label_table* }
lk_offset: 0 . . 256;   { smallest offset value that might work }
t: 0 . . ´77777;   { label value that is being redirected }
extra_loc_needed: *boolean*;   { do we need a special word for *bchar*? }

168.   ⟨Compute the ligature/kern program offset 168⟩ ≡
  ⟨Insert all labels into *label_table* 169⟩;
  if *bchar* < 256 **then**
     begin *extra_loc_needed* ← *true*; *lk_offset* ← 1;
     end
  else begin *extra_loc_needed* ← *false*; *lk_offset* ← 0;
     end;
  ⟨Find the minimum *lk_offset* and adjust all remainders 170⟩;
  if *bchar_label* < ´77777 **then**
     begin *lig_kern*[*nl* − 1].*b2* ← (*bchar_label* + *lk_offset*) **div** 256;
     lig_kern[*nl* − 1].*b3* ← (*bchar_label* + *lk_offset*) **mod** 256;
     end

This code is used in section 159.

169.   ⟨Insert all labels into *label_table* 169⟩ ≡
  label_ptr ← 0; *label_table*[0].*rr* ← −1;   { sentinel }
  for *c* ← *bc* **to** *ec* **do**
     if *char_tag*[*c*] = *lig_tag* **then**
        begin *sort_ptr* ← *label_ptr*;   { there's a hole at position *sort_ptr* + 1 }
        while *label_table*[*sort_ptr*].*rr* > *char_remainder*[*c*] **do**
           begin *label_table*[*sort_ptr* + 1] ← *label_table*[*sort_ptr*]; *decr*(*sort_ptr*);   { move the hole }
           end;
        label_table[*sort_ptr* + 1].*cc* ← *c*; *label_table*[*sort_ptr* + 1].*rr* ← *char_remainder*[*c*]; *incr*(*label_ptr*);
        end

This code is used in section 168.

170.   ⟨Find the minimum *lk_offset* and adjust all remainders 170⟩ ≡
  begin *sort_ptr* ← *label_ptr*;   { the largest unallocated label }
  if *label_table*[*sort_ptr*].*rr* + *lk_offset* > 255 **then**
     begin *lk_offset* ← 0; *extra_loc_needed* ← *false*;   { location 0 can do double duty }
     repeat *char_remainder*[*label_table*[*sort_ptr*].*cc*] ← *lk_offset*;
        while *label_table*[*sort_ptr* − 1].*rr* = *label_table*[*sort_ptr*].*rr* **do**
           begin *decr*(*sort_ptr*); *char_remainder*[*label_table*[*sort_ptr*].*cc*] ← *lk_offset*;
           end;
        incr(*lk_offset*); *decr*(*sort_ptr*);
     until *lk_offset* + *label_table*[*sort_ptr*].*rr* < 256;
           { N.B.: *lk_offset* = 256 satisfies this when *sort_ptr* = 0 }
     end;
  if *lk_offset* > 0 **then**
     while *sort_ptr* > 0 **do**
        begin *char_remainder*[*label_table*[*sort_ptr*].*cc*] ← *char_remainder*[*label_table*[*sort_ptr*].*cc*] + *lk_offset*;
        decr(*sort_ptr*);
        end;
  end

This code is used in section 168.

171. ⟨Output the ligature/kern program 171⟩ ≡
  if *extra_loc_needed* **then**   { *lk_offset* = 1 }
    begin *out*(255); *out*(*bchar*); *out*(0); *out*(0);
    end
  else for *sort_ptr* ← 1 **to** *lk_offset* **do**   { output the redirection specs }
      begin *t* ← *label_table*[*label_ptr*].*rr*;
      if *bchar* < 256 **then**
        begin *out*(255); *out*(*bchar*);
        end
      else begin *out*(254); *out*(0);
        end;
      out_size(*t* + *lk_offset*);
      repeat *decr*(*label_ptr*);
      until *label_table*[*label_ptr*].*rr* < *t*;
      end;
  if *nl* > 0 **then**
    for *lig_ptr* ← 0 **to** *nl* − 1 **do**
      begin *out*(*lig_kern*[*lig_ptr*].*b0*); *out*(*lig_kern*[*lig_ptr*].*b1*); *out*(*lig_kern*[*lig_ptr*].*b2*);
      out(*lig_kern*[*lig_ptr*].*b3*);
      end;
  if *nk* > 0 **then**
    for *krn_ptr* ← 0 **to** *nk* − 1 **do** *out_scaled*(*kern*[*krn_ptr*])
This code is used in section 157.

172. ⟨Output the extensible character recipes 172⟩ ≡
  if *ne* > 0 **then**
    for *c* ← 0 **to** *ne* − 1 **do**
      begin *out*(*exten*[*c*].*b0*); *out*(*exten*[*c*].*b1*); *out*(*exten*[*c*].*b2*); *out*(*exten*[*c*].*b3*);
      end;
This code is used in section 157.

173.   For our grand finale, we wind everything up by outputting the parameters.

⟨Output the parameters 173⟩ ≡
  for *par_ptr* ← 1 **to** *np* **do**
    begin if *par_ptr* = 1 **then** ⟨Output the slant (*param*[1]) without scaling 174⟩
    else *out_scaled*(*param*[*par_ptr*]);
    end
This code is used in section 157.

174. ⟨Output the slant (*param*[1]) without scaling 174⟩ ≡
  begin if *param*[1] < 0 **then**
    begin *param*[1] ← *param*[1] + ´10000000000; *out*((*param*[1] **div** ´100000000) + 256 − 64);
    end
  else *out*(*param*[1] **div** ´100000000);
  out((*param*[1] **div** ´200000) **mod** 256); *out*((*param*[1] **div** 256) **mod** 256); *out*(*param*[1] **mod** 256);
  end
This code is used in section 173.

175.   The VF output phase.   Output to *vf_file* is considerably simpler.

define *id_byte* = 202   { current version of VF format }
define *vout*(#) ≡ *write*(*vf_file*, #)

⟨ Globals in the outer block 5 ⟩ +≡
vcount: *integer*;   { number of bytes written to *vf_file* }

176.   We need a routine to output integers as four bytes. Negative values will never be less than -2^{24}.

procedure *vout_int*(*x* : *integer*);
  begin if $x \geq 0$ **then** *vout*(*x* **div** ´100000000)
  else begin *vout*(255); $x \leftarrow x + $´100000000;
    end;
  vout((*x* **div** ´200000) **mod** 256); *vout*((*x* **div** ´400) **mod** 256); *vout*(*x* **mod** 256);
  end;

177.   ⟨ Do the VF output 177 ⟩ ≡
  vout(*pre*); *vout*(*id_byte*); *vout*(*vtitle_length*);
  for $k \leftarrow 0$ **to** *vtitle_length* − 1 **do** *vout*(*vf*[*vtitle_start* + *k*]);
  for $k \leftarrow $ *check_sum_loc* **to** *design_size_loc* + 3 **do** *vout*(*header_bytes*[*k*]);
  vcount ← *vtitle_length* + 11;
  for *cur_font* ← 0 **to** *font_ptr* − 1 **do** ⟨ Output a local font definition 178 ⟩;
  for *c* ← *bc* **to** *ec* **do**
    if *char_wd*[*c*] > 0 **then** ⟨ Output a packet for character *c* 179 ⟩;
  repeat *vout*(*post*); *incr*(*vcount*);
  until *vcount* **mod** 4 = 0
This code is used in section 180.

178.   ⟨ Output a local font definition 178 ⟩ ≡
  begin *vout*(*fnt_def1*); *vout*(*cur_font*);
  vout(*font_checksum*[*cur_font*].*b0*); *vout*(*font_checksum*[*cur_font*].*b1*); *vout*(*font_checksum*[*cur_font*].*b2*);
  vout(*font_checksum*[*cur_font*].*b3*); *vout_int*(*font_at*[*cur_font*]); *vout_int*(*font_dsize*[*cur_font*]);
  vout(*farea_length*[*cur_font*]); *vout*(*fname_length*[*cur_font*]);
  for $k \leftarrow 0$ **to** *farea_length*[*cur_font*] − 1 **do** *vout*(*vf*[*farea_start*[*cur_font*] + *k*]);
  if *fname_start*[*cur_font*] = *vf_size* **then**
    begin *vout*("N"); *vout*("U"); *vout*("L"); *vout*("L");
    end
  else for $k \leftarrow 0$ **to** *fname_length*[*cur_font*] − 1 **do** *vout*(*vf*[*fname_start*[*cur_font*] + *k*]);
  vcount ← *vcount* + 12 + *farea_length*[*cur_font*] + *fname_length*[*cur_font*];
  end
This code is used in section 177.

179.   ⟨Output a packet for character c 179⟩ ≡

  begin $x \leftarrow memory[char\_wd[c]]$;

  if $design\_units \neq unity$ **then** $x \leftarrow round((x/design\_units) * 1048576.0)$;

  if $(packet\_length[c] > 241) \vee (x < 0) \vee (x \geq \text{´}100000000)$ **then**

    begin $vout(242)$; $vout\_int(packet\_length[c])$; $vout\_int(c)$; $vout\_int(x)$;

    $vcount \leftarrow vcount + 13 + packet\_length[c]$;

    end

  else begin $vout(packet\_length[c])$; $vout(c)$; $vout(x \text{ div } \text{´}200000)$; $vout((x \text{ div } \text{´}400) \text{ mod } 256)$;

    $vout(x \text{ mod } 256)$; $vcount \leftarrow vcount + 5 + packet\_length[c]$;

    end;

  if $packet\_start[c] = vf\_size$ **then**

    begin if $c \geq 128$ **then** $vout(set1)$;

    $vout(c)$;

    end

  else for $k \leftarrow 0$ **to** $packet\_length[c] - 1$ **do** $vout(vf[packet\_start[c] + k])$;

  end

This code is used in section 177.

180. The main program.   The routines sketched out so far need to be packaged into separate procedures, on some systems, since some Pascal compilers place a strict limit on the size of a routine. The packaging is done here in an attempt to avoid some system-dependent changes.

procedure *param_enter*;
 begin ⟨ Enter the parameter names 57 ⟩;
 end;

procedure *vpl_enter*;
 begin ⟨ Enter all the VPL names 56 ⟩;
 end;

procedure *name_enter*;   { enter all names and their equivalents }
 begin ⟨ Enter all the PL names and their equivalents, except the parameter names 55 ⟩;
 vpl_enter; *param_enter*;
 end;

procedure *read_lig_kern*;
 var *krn_ptr*: 0 . . *max_kerns*;   { an index into *kern* }
  c: *byte*;   { runs through all character codes }
 begin ⟨ Read ligature/kern list 109 ⟩;
 end;

procedure *read_char_info*;
 var *c*: *byte*;   { the char }
 begin ⟨ Read character info list 118 ⟩;
 end;

procedure *read_input*;
 var *c*: *byte*;   { header or parameter index }
 begin ⟨ Read all the input 92 ⟩;
 end;

procedure *corr_and_check*;
 var *c*: 0 . . 256;   { runs through all character codes }
  hh: 0 . . *hash_size*;   { an index into *hash_list* }
  lig_ptr: 0 . . *max_lig_steps*;   { an index into *lig_kern* }
  g: *byte*;   { a character generated by the current character *c* }
 begin ⟨ Correct and check the information 139 ⟩
 end;

procedure *vf_output*;
 var *c*: *byte*;   { runs through all character codes }
  cur_font: 0 . . 256;   { runs through all local fonts }
  k: *integer*;   { loop index }
 begin ⟨ Do the VF output 177 ⟩;
 end;

181.   Here is where VPtoVF begins and ends.

 begin *initialize*;
 name_enter;
 read_input; *print_ln*(´.´);
 corr_and_check;
 ⟨ Do the TFM output 157 ⟩;
 vf_output;
 end.

182.   System-dependent changes.   This section should be replaced, if necessary, by changes to the program that are necessary to make `VPtoVF` 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.

183.   Index.   Pointers to error messages appear here together with the section numbers where each identifier is used.

⟨Assemble a font selection 126⟩   Used in section 125.
⟨Assemble a horizontal movement 130⟩   Used in section 125.
⟨Assemble a rulesetting instruction 129⟩   Used in section 125.
⟨Assemble a special command 134⟩   Used in section 125.
⟨Assemble a stack pop 133⟩   Used in section 125.
⟨Assemble a stack push 132⟩   Used in section 125.
⟨Assemble a typesetting instruction 127⟩   Used in section 125.
⟨Assemble a vertical movement 131⟩   Used in section 125.
⟨Check for infinite ligature loops 154⟩   Used in section 139.
⟨Check ligature program of c 149⟩   Used in sections 139 and 140.
⟨Check the pieces of $exten[c]$ 141⟩   Used in section 140.
⟨Compute the check sum 163⟩   Used in section 162.
⟨Compute the command parameters y, cc, and zz 151⟩   Used in section 150.
⟨Compute the hash code, cur_hash, for cur_name 51⟩   Used in section 50.
⟨Compute the ligature/kern program offset 168⟩   Used in section 159.
⟨Compute the twelve subfile sizes 159⟩   Used in section 157.
⟨Constants in the outer block 3⟩   Used in section 2.
⟨Convert $xxx1$ command to $xxx4$ 135⟩   Used in section 134.
⟨Correct and check the information 139⟩   Used in section 180.
⟨Declare the vf_fix procedure 128⟩   Used in section 124.
⟨Do the TFM output 157⟩   Used in section 181.
⟨Do the VF output 177⟩   Used in section 180.
⟨Doublecheck the lig/kern commands and the extensible recipes 155⟩   Used in section 139.
⟨Enter all the PL names and their equivalents, except the parameter names 55⟩   Used in section 180.
⟨Enter all the VPL names 56⟩   Used in section 180.
⟨Enter the parameter names 57⟩   Used in section 180.
⟨Find the minimum lk_offset and adjust all remainders 170⟩   Used in section 168.
⟨For all characters g generated by c, make sure that $char\_wd[g]$ is nonzero, and set $seven\_unsafe$ if
      $c < 128 \leq g$ 140⟩   Used in section 139.
⟨Globals in the outer block 5, 21, 24, 27, 29, 31, 36, 44, 46, 47, 52, 67, 75, 77, 82, 86, 89, 91, 113, 123, 138, 143, 147, 158,
      161, 167, 175⟩   Used in section 2.
⟨Initialize a new local font 105⟩   Used in section 104.
⟨Insert all labels into $label\_table$ 169⟩   Used in section 168.
⟨Local variables for initialization 25, 48, 79, 83⟩   Used in section 2.
⟨Make sure that c is not the largest element of a charlist cycle 142⟩   Used in section 139.
⟨Make sure the ligature/kerning program ends appropriately 145⟩   Used in section 139.
⟨Multiply by 10, add $cur\_char -$ "0", and get_next 74⟩   Used in section 72.
⟨Multiply by r, add $cur\_char -$ "0", and get_next 70⟩   Used in section 69.
⟨Output a local font definition 178⟩   Used in section 177.
⟨Output a packet for character c 179⟩   Used in section 177.
⟨Output the character info 164⟩   Used in section 157.
⟨Output the dimensions themselves 166⟩   Used in section 157.
⟨Output the extensible character recipes 172⟩   Used in section 157.
⟨Output the header block 162⟩   Used in section 157.
⟨Output the ligature/kern program 171⟩   Used in section 157.
⟨Output the parameters 173⟩   Used in section 157.
⟨Output the slant ($param[1]$) without scaling 174⟩   Used in section 173.
⟨Output the twelve subfile sizes 160⟩   Used in section 157.
⟨Print c in octal notation 137⟩   Used in section 118.
⟨Put the width, height, depth, and italic lists into final form 144⟩   Used in section 139.
⟨Read a character property 119⟩   Used in section 118.
⟨Read a font property value 94⟩   Used in section 92.