The Tao of Fonts

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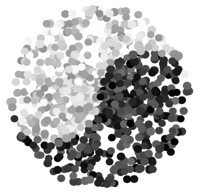


Abstract

Fonts are collections of symbols which allow people to express what they want to say, what they think or feel. Writing is a technique and as each technique has something to offer and has limitations. For example, the shapes of symbols depend on the tools and materials used for writing.

In the first part, I illustrate some writing techniques with examples. In the second part, I present a new technique for creating fonts and illustrate it with several examples. It is based on the METAPOST language [1] and could be viewed as Knuth's method [2–5] adapted to METAPOST. Knuth uses METAFONT to program fonts and an mf compiler to translate programs into bitmap fonts. Unfortunately, today's standards are based on PostScript fonts [6–9]. So, to keep the Knuth's idea of programmable shapes alive, fonts should be programmed in PostScript. This is difficult, because PostScript is a low level language.

The approach presented here is to program fonts in METAPOST. Although the mpost compiler is not able to output a font directly, its output can be assembled into a PostScript font [10–13]. A font programming environment is based on a revised version of the mft pretty-printer. The original mft understands only METAFONT, but changed mft understands METAPOST too.

In the third part, I present a simple font programmed as a Type 3 and as a Type 1 font. These examples will give an idea of font programming.

In the Appendix, I present a detailed description of Type 3 fonts [6, 9].

Typographical journey

Exploring type [with computer] is fun, and ultimately, it changes the way you think about type and work with it.
— ROB CARTER, Experimental Typography

Throughout history people used have symbols to visually encode thoughts and feelings. The oldest example I was able to find in the literature is an inscription from La Pasiega cave.

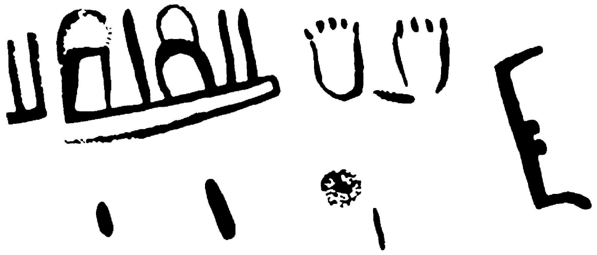


Fig. 1. Inscription from La Pasiega cave (Spain, ca. 10000 B.C.)

Unfortunately, the meaning of the symbols was lost in the past, so that we don't know how to decode this inscription. As a result, we don't know exactly what it means — we can only guess. Other ancient symbols are found on pikes and bows. It is assumed that they are some kind of owner's signature or that they have a magical value, so that they bring luck to the owner, etc. Nowadays, we still use symbols in similar way. Probably everyone has at least once received a mail overprinted with "CONFIDENTIAL – you have been chosen to be rich. You can take part in our lottery draw. All you have to do is to subscribe our magazine."

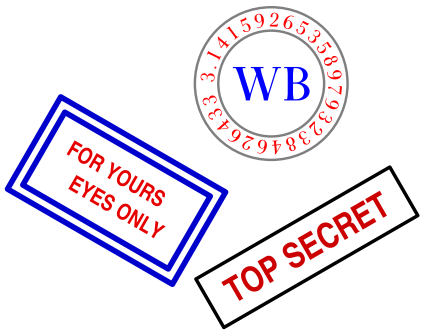


Fig. 2. 'Magical' stamps

Pictographs, ideograms, and alphabets have been written and reproduced on papyrus, stones, wood, clay tablets, paper, and computer displays;

and different techniques have been used to write, carve, cut, and print symbols.

Handwriting used to be the most common technique. The Phoenicians invented an alphabetic font which is a precursor of the Greek, Latin, and Cyrillic fonts. The inscription of Fig. 3 was originally written on papyrus.

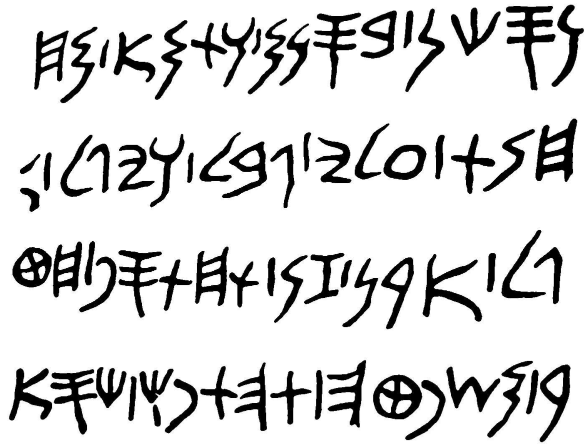


Fig. 3. Phoenician inscription (Byblos, 1100 B.C.)

Handwriting can reveal the author's personality, which makes this technique interesting. Wouldn't it be nice to have a psychological portrait of this author?

Fig. 4 shows a fragment of a poem written by probably the greatest Polish poet Cyprian Kamil Norwid. This poem seems to move every Pole who reads it. I think that the same poem printed along with several others in Computer Modern, Garamond, Times, or Palatino would not have the same impact on readers. Maybe this is why I don't like reading poems which all look the same.†

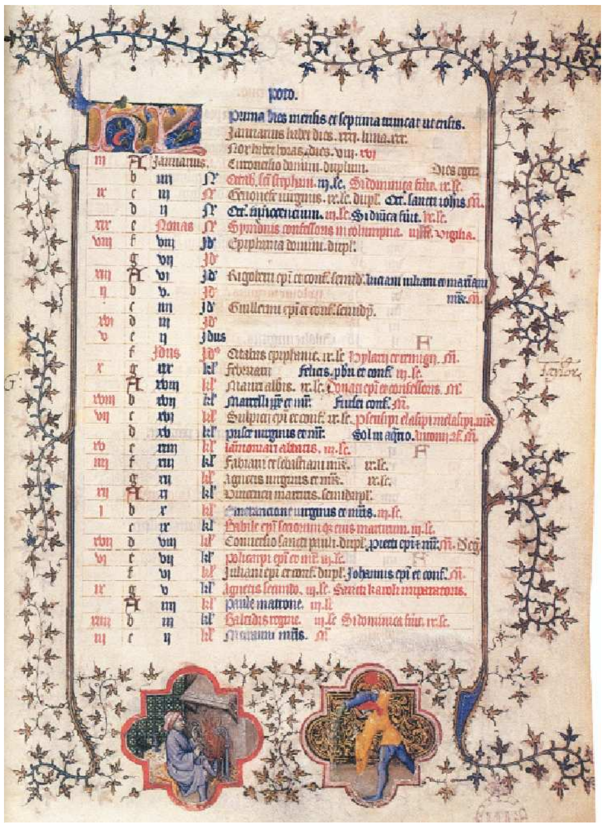


Fig. 5. *Calendarium Parisiense* (manuscript Latin, ca. 1425)

But the main problem caused by handwriting (and computer typesetting too) is the appearance of overfull and underfull lines. These, in some cases, can not be eliminated. Fig. 5 shows the earliest example I was able to find.

Another technique is cutting in stone. The shapes in Fig. 6 are more regular, partly because bigger letters were sketched beforehand.

This picture shows the earliest example of serifs ever found. The serifs are functioning here as a way of finishing letters, which otherwise would be irregular and wiggly ended. Nowadays, we think that serif fonts are easier and quicker to read. This is generally true, because letters without serifs in some cases looks similar to each other, for example: I – l – 1.*

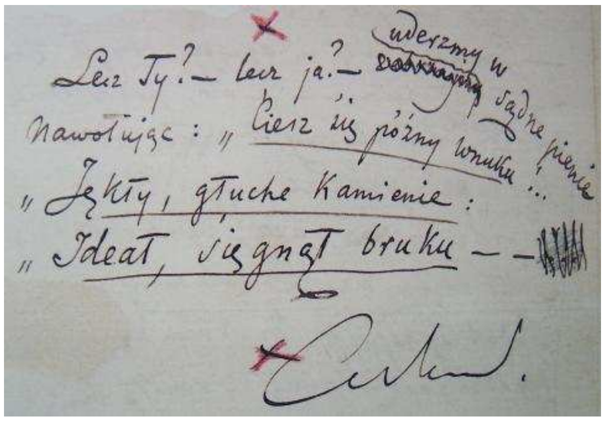

Lecz Ty?— lecz ja?— ~~[illegible]~~ uderzmy w sądne pienie
Nawołując: „Lecz się, późny wnuku!...
„Jękły, głuche Kamienie:
„Ideał, sięgnął bruku — —
[illegible]

Fig. 4. Cyprian K. Norwid, *Vade-mecum* (manuscript in Polish, 1865–1866)

† But I would be very grateful if my doctor chose to use Computer Modern on my prescriptions.

* I cannot imagine books or newspapers carved in stone. Nevertheless, there was once an exception: I have seen Fred Flintstone reading newspapers. But this was a long time ago down in the Bed Rock.

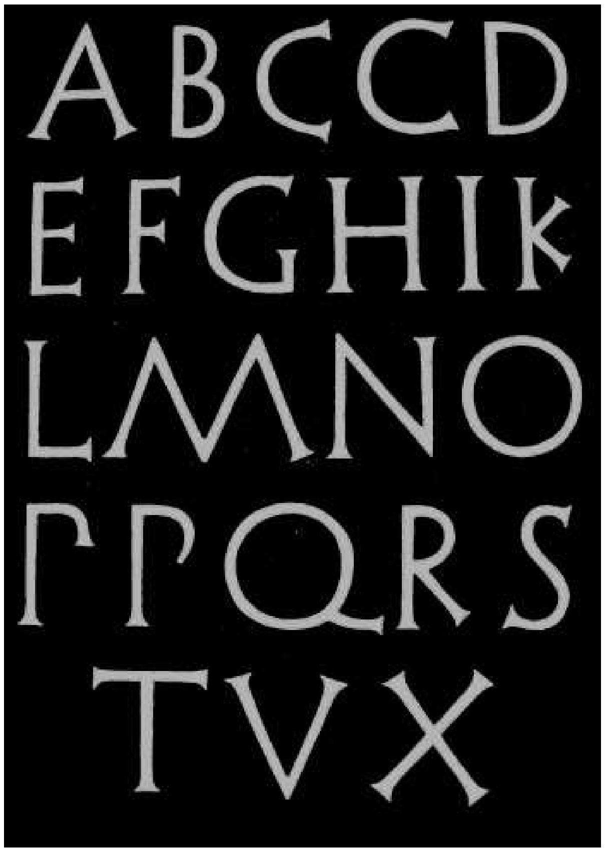
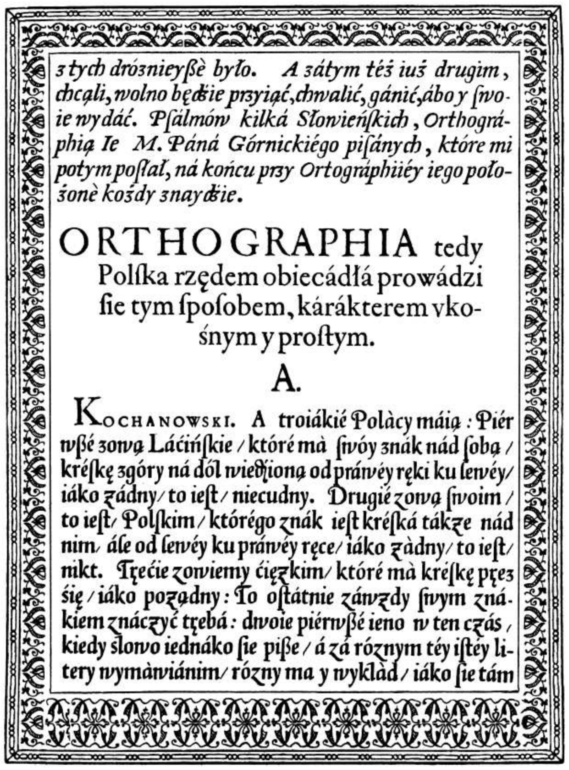


Fig. 6. Rome, (ca. 200 B.C.)



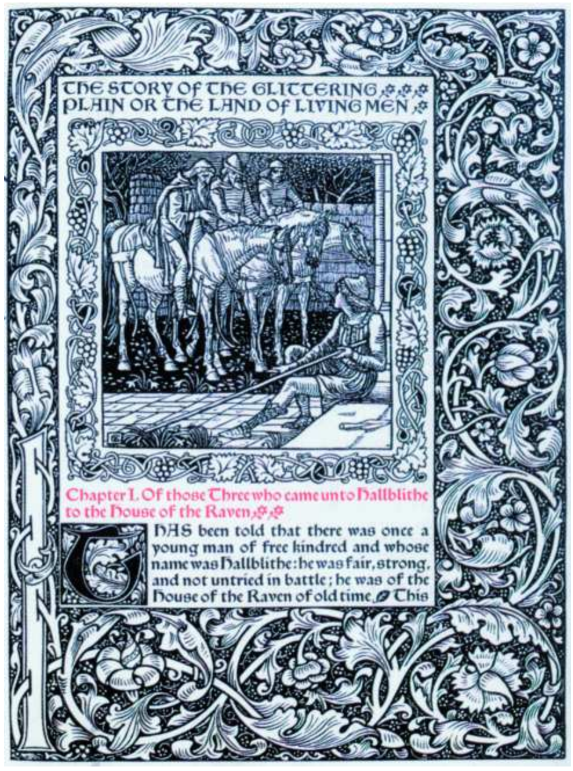
ʒ tych dróʒnieyſzè było. A ʒátym téʒ iuʒ drugim, chcąli, wolno będźie przyiąć, chwalić, gánić, ábo y ſwo-ie wydáć. Pſálmów kilká Słowieńſkich, Orthográ-phią Ie M. Páná Górnickiégo piſánych, które mi potym poſłał, ná końcu przy Ortográphiiéy iego położonè koʒdy ʒnaydźie.

ORTHOGRAPHIA tedy
Polſka rzędem obiecádłá prowádzi
ſie tym ſpoſobem, kárákterem vko-
śnym y proſtym.

A.

KOCHANOWSKI. A troiákié Polàcy máią: Piér-wſzé ʒową Láćińſkie / które mà ſwóy ʒnák nád ſobą / kréſkę ʒgóry ná dół wiedźioną od práwéy ręki ku lewéy / iáko ʒádny / to ieſt / niecudny. Drugié ʒową ſwoim / to ieſt / Polſkim / którégo ʒnák ieſt kréſká tákʒe nád nim / ále od lewéy ku práwéy ręce / iáko ʒàdny / to ieſt / nikt. Tʒećie ʒowiemy ćięʒkim / które mà kréſkę pʒeʒ śię / iáko poʒądny: To oſtátnie záwʒdy ſwym ʒná-kiem ʒnáczyć tʒebá: dwoie piérwſzé ieno w ten cʒás, kiedy słowo iednáko ſie piſze / á ʒá róʒnym téy iſtéy li-tery wymàwiánim / róʒny ma y wykłàd / iáko ſie tám

Fig. 7. *New Polish Character*
(Jan Januszowski, 1594 Cracow)



THE STORY OF THE GLITTERING
PLAIN OR THE LAND OF LIVING MEN

Chapter I. Of those Three who came unto Hallblithe to the House of the Raven

THAS been told that there was once a young man of free kindred and whose name was Hallblithe: he was fair, strong, and not untried in battle; he was of the House of the Raven of old time. This

Fig. 8. *The Story of the Glittering Plain*
(Kelmscott Press, 1891)

Fig. 7 shows the 32nd page of one of the first printed books in Poland. This book is very important, because it contains designs for Polish diacritics: aogonek, eogonek etc. The borders were cut in wood and letters in metal. The printed letters are much smaller than carved ones, so cutting them was a real challenge, yet even tiny serifs are present. This technique was perfected over the years. The results are seen on Fig. 8. Here borders were cut in wood and the type was cut in metal.

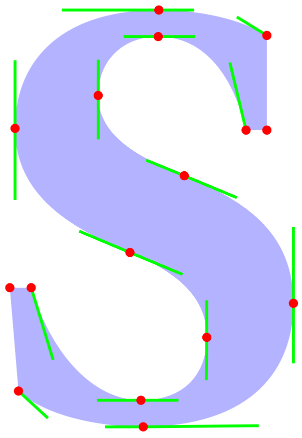
Finally we get to Fig. 9 showing what computers are good at. The 'shapes', drawn by a computer, are almost ideal. Typographical embellishments are not present — instead the letters are colored and a background photo is used to improve the typography of the page.

Each new technique starts from the point where the old one ends.

When we make a letter with a computer, the mouse is used to put points on an 'imaginary sheet'. As the points are laid down, the computer joins them with curves. Next, the inflexion points (red) and the endings of tangents (green lines) are adjusted by hand. At the same time, the computer

PLAYBOY
Wywiad z Anthony Hopkinsem
Reporter PLAYBOYA Porno w Polsce
Słowo prawdy o ojcu Rydzyku
Pan tuli pana pierwszy ślub gejów
Izabella Łukomska
PLAYMATE ROKU

Fig. 9. “Playboy” (Polish edition, 2001)



```
newpath
487 499 moveto
451 499 lineto
423 616 363 661 299 661 curveto
239 661 195 621 195 559 curveto
195 483 278 447 344 420 curveto
435 382 533 331 533 199 curveto
533 95 473 -13 273 -15 curveto
207 -15 108 0 57 47 curveto
42 226 lineto
79 226 lineto
117 101 193 31 269 31 curveto
334 31 382 66 383 140 curveto
383 204 341 249 250 287 curveto
162 324 51 378 51 502 curveto
51 620 132 707 300 707 curveto
361 707 435 695 487 663 curveto
487 499 lineto
closepath
fill
```

Fig. 10

redraws the shape (see Fig. 10). We have replaced a chisel by a mouse and wood/metal by the computer screen. With these tools, we can polish the shape as long as we wish, and we can not ruin the shape with the one wrong decision as can happen with traditional tools and materials.

One of the limitations of this technique is shown in Fig. 11. Printing a symbol by computer means putting the imaginary sheet on the screen. This sheet can be expanded, contracted, or skewed — we can apply any geometrical transformation to it. Unfortunately, the results may not be satisfactory;

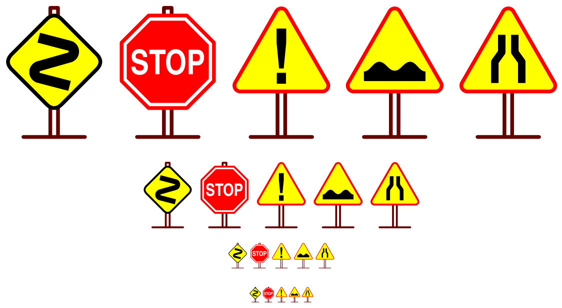


Fig. 11

for example, the stop sign in the third row has lost its white border and the inscription is hardly readable. We could repair this if it would be possible to drop the border and scale the inscription less, but the operation is unfeasible, because the computer does not know which numbers in the character design are responsible for the border and which for the inscription.

So the only way to produce a better font at small sizes is to make it from scratch. Since some will inevitably use an enlarged version of this font instead of the original one, and chaos will ensue. Imagine a country where each town has slightly different traffic signs!

Programming fonts

Typographic standards make type more readable, but readability has become a relative concept. The immediacy of personal computers and the World Wide Web has raised the level of ‘typographic literacy’: computers are used to stretch typographic boundaries [14].

Before we start to explore type with computers, we should ask: *What is the right way to create digitized patterns for printing or displaying?* In this section, I will try to convey some of my excitement about experiments with the tools I have created, since I think that I am going in the right direction [see also 3].

To play with and to explore fonts I use a set of UNIX tools. To this set I added the DOS batch files forming the METATYPE1 package by the JNS team [11], which I converted to UNIX scripts.

The language for font programming is METAPOST. To make a METAPOST font usable we must convert it into something that printing and typesetting systems can understand. I chose PostScript Type 1 or Type 3 font programs, mainly because Ghostscript — a free PostScript interpreter — is available on almost every computer platform.

The Linux version of the tools consists of METAPOST font libraries and four scripts:

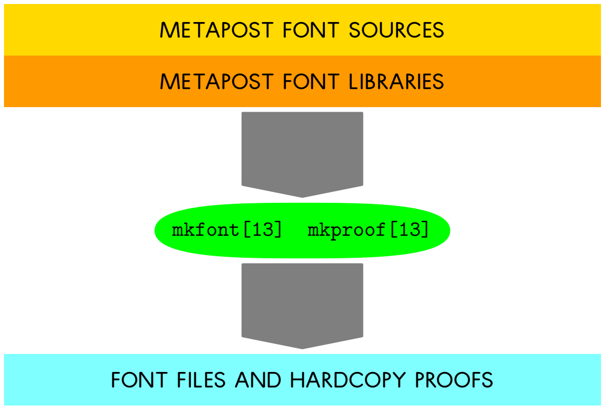


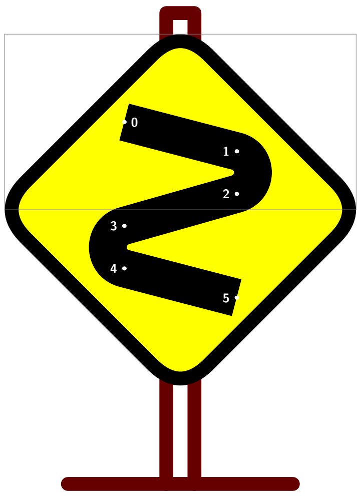
Fig. 12. Fonts programming

`mkfont1` – converts METAPOST font sources to Type 1 font: a shell script that uses programs `mpost`, `t1asm` from the t1utils package and `awk`.

`mkfont3` – converts METAPOST font sources to Type 3 font; a perl script that calls `mpost`

`mkproof1` and `mkproof3` – scripts that produce hardcopy proofs and are used as debugging tools: they call `mpost` and the `mft` pretty-printer.

SIGN-000.MP



```
beginpic(127, 250, 125, 0);  "Dangerous␣bend";
    draw post;  draw info_signboard;
    clearxy;
    % the dangerous bend
    numeric heavyline;  heavyline := 27;
    x5 = w − x0;  x5 − x0 = 80;  x1 = x2 = x5;  x0 = x3 = x4;
    y0 = −y5 = 1/2 h;  y1 = −y4 = 1/3 h;  y2 = −y3 = 1/11 h;
    pickup pencircle scaled heavyline;
    interim linecap := butt;
    draw z0 -- z1{z1 − z0} .. z2 --- z3 .. z4{z5 − z4} -- z5
        withcolor c.Dangerous Bend;
    labelcolor := white;  dotcolor := white;
    labels lft(1, 2, 3, 4, 5);  labels rt(0);
endpic;
```

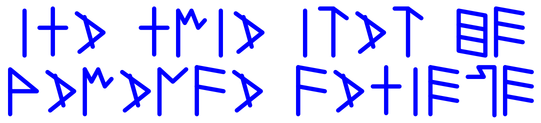
11:57 11 VII 2001 *7*

Fig. 13. Hardcopy proof of the dangerous bend

In font programming two type of errors appear: bugs in font program and design errors. Bugs are treated in an ordinary way. To catch design errors I use hardcopy produced by the `mft` program.

We have the tools, so it's high time to start programming. Let's start from the beginning.

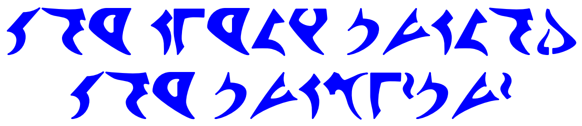
The Phoenician font lacks vowels. There are three ways of writing with this font. Lines may be written from left to right, right to left, or left to right, right to left, etc., with letters on every other line reflected vertically. It could be a real challenge to typeset a Phoenician script with TEX.



To [our] Lady Ishtar
This is the holy place

Fig. 14. Phoenician font [26]

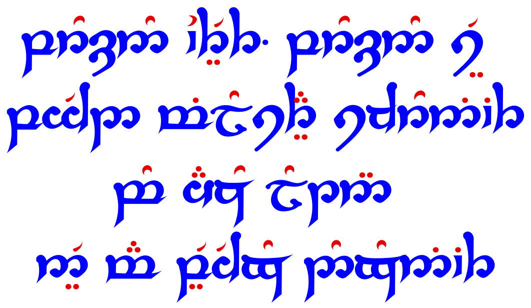
TEX could be used to communicate with the STAR TREK crew: we only need their font. No problem: there is nothing special about this font, except the extraordinary shapes of the symbols and the use of few ligatures.



Listen sons of Kahless!
Listen his daughters!

Fig. 15. Klingon font [23]

We can also send our classic love poems to elves. The elves write vowels over the preceding letter, unless it is also a vowel. This case, and the case when a vowel starts a word, are handled by other rules [18].



— JAN KOCHANOWSKI, *About love*

Fig. 16. Tengwar font [24]

It appears that that all these rules can be implemented with an appropriate ligature and kerning table.

What was considered unreadable yesterday is readable today. People are more visually sophisticated and typographically savvy than ever before, so my next font contains ideograms for love and for some other emotions, as well as letters.

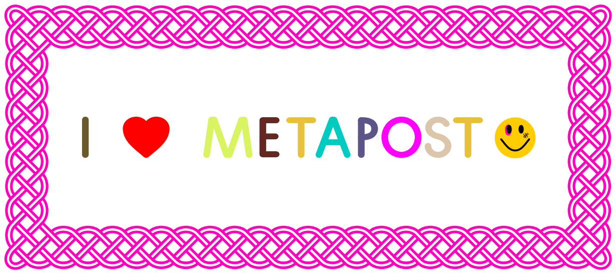


Fig. 17. Redis font (see also [28])

Special math fonts can be useful, too. We could use them on title pages or on slides. In the example below, math characters are colored according to their math class as defined in plain format. Below, binary operators are painted in green, large operators in magenta, etc. (In the pdf version, not on paper.)

$$M = \begin{array}{c} \\ C \\ I \\ C' \end{array} \!\!\left(\begin{array}{ccc} C & I & C' \\ 1 & 0 & 0 \\ \beta & 1-\beta & 0 \\ 0 & \xi & 1-\xi \end{array}\right)$$

$$\begin{aligned} \left(\int_{-\infty}^{\infty} e^{-x^2}\,dx\right)^2 &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} e^{-(x^2+y^2)}\,dx\,dy \\ &= \int_0^{2\pi}\int_0^{\infty} e^{-r^2}\,r\,dr\,d\theta \\ &= \int_0^{2\pi}\left(-\frac{e^{-r^2}}{2}\Bigg|_{r=0}^{r=\infty}\right)d\theta \\ &= \pi \qquad (78) \end{aligned}$$

Fig. 18. New Punk Math font (see also [19])

Fig. 19 shows a piece of text typeset with a computer replica of the font used in the Polish Alphabet Primer by Falski. I learned to write letters with the help of Falski's primer, as did my wife and my daughter. In fact, all children in Poland learn Falski's letters.

DIALOGS ARE REWRITTEN AGAIN
TO SPARE THE AUTHOR AND THE
OTHER CHARACTERS THE SHAME OF
SOUNDING AS INARTICULATE AS
THEY INVARIABLY DO OR WOULD IF
THEIR SENTENCES ALMOST INVARIABLY
BEGUN WITH THE WORD DUDE
AS IN FOR EXAMPLE DUDE SHE
DIED WERE MERELY TRANSCRIBED

Fig. 19. Ala font [27]

The characteristic features of this font are listed below:

- size of characters: BIG,
- width: PROPORTIONAL,
- slanting: UPRIGHT,
- interletter spacing: BIG,
- uniformity of pressure: CONSTANT,
- strength of pressure: AVERAGE,
- interword spacing: BIG,
- overall appearance: OVAL,
- readability: CLEAR.

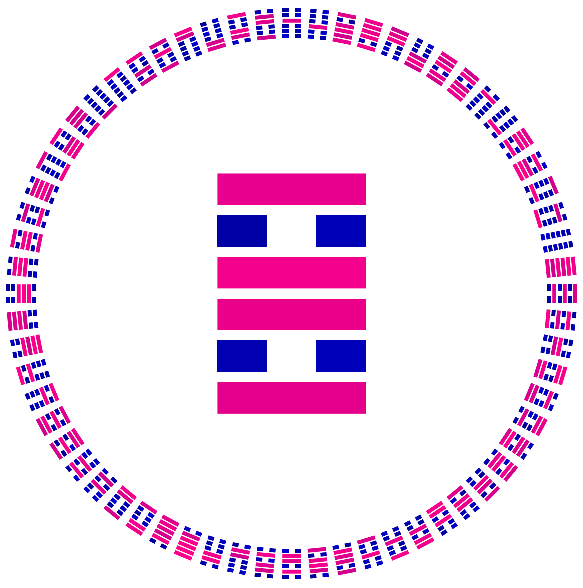
Handwriting can reveal the personality of the writer. The writer in this case is my computer so we can get 'his' psychological portrait easily: *A person which writes this way is well-wishing, Easy to cooperate with and friendly. Usage of uppercase letters and big interletter spacing indicates this. Constant pressure means emotional maturity. Oval appearance might mean uncertainty and submissiveness. Finally, constant and average pressure and wide characters indicate an uneasy and over excitable person.*

The most important thing about this example is how easy it is to make this font to look differently, for example more 'technical'. It suffices to change few numbers which define this font. But it would be difficult to simulate other important features of handwritten scripts, such as variable baseline, variable letters shape, pressure of script.

The next example shows the I-Ching font (see also [29]). The I Ching or "The Book of Changes" is an old Chinese oracle. This font could be used to do divinations. With computers it is easy. Ask a question, press Enter key and your computer will do the rest. On the next page I put results obtained

LI

To Shine Brightly, to Part



INTERPRETATION

To Part. It is useful to stand firm and behave well. This will bring success. Take care of the cows. There will be good fortune.

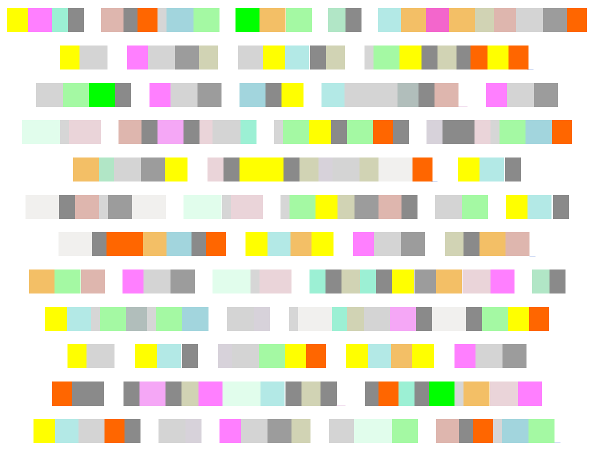
Interpretation of the 4 th change line

It comes unexpectedly. It is like a fire which dies down and is discarded.

during my presentation at the TUG 2002 meeting in Trivandrum.

Nowadays, children in Poland have more and more problems with orthography. There are many pairs of letters which cause them problems. For example the letters 'oacute' and 'u' are pronounced the same way, 'b' and 'p' are pronounced almost the same way, etc. The following trick is used to teach orthography to children with dyslexia [22]. Each problematic letter is mapped to a crayon with different colors corresponding to different letters. Instead of writing a problematic letter, the child uses the appropriate crayon to draw a rectangle. After a while the crayons are removed. This method is supplemented by appropriate books and dictionaries.

The following 'text' demonstrates the extreme case in which every letter is problematic.



I like this kind of writing, so why take off crayons?

TYPE DESIGN CAN BE HAZARDOUS
TO YOUR OTHER INTERESTS.
ONCE YOU GET HOOKED, YOU
WILL DEVELOP INTENSE FEELINGS
ABOUT LETTERFORMS. THE
MEDIUM WILL INTRUDE ON THE
MESSAGES THAT YOU READ.
AND YOU WILL PERPETUALLY BE
THINKING OF IMPROVEMENTS
TO THE FONTS THAT YOU
SEE EVERYWHERE, ESPECIALLY
THOSE OF YOUR OWN DESIGN.

— DONALD E. KNUTH, The METAFONTbook

Type 3 font example

Fonts are collections of programmed shapes. There are several kinds of fonts. Each type of font has its own convention for organizing and representing the information within it. The PostScript language defines the following types of fonts [8, p. 322]: 0, 1, 2, 3, 9, 10, 11, 14, 32, 42. Text fonts are mostly of Type 1, which are programmed with special procedures. To execute efficiently and to produce more legible output, these procedures use features common to collections of black & white letter-like shapes. The procedures may not be used outside a Type 1 font. While any graphics symbol may be programmed as a character in a Type 1 font, non-letter shaped symbols are better served by the Type 3 font program which defines shapes with ordinary PostScript procedures including those which produce color. Other font types are used infrequently.

Although Type 3 fonts are PostScript programs, I prefer to program shapes in the METAPOST language and convert the `mpost` output into a Type 3 font, because METAPOST simplifies the programming due to its declarative nature. In PostScript each curve is built from lines, arcs of circle and Beziér curves [p. 393, 9]. For complicated shapes this requires a lot of nontrivial programming. METAPOST implements a 'magic recipe' [10] for joining points in a pleasing way, which helps a lot. Even if you are not satisfied with the shape, you can give the program various hints about what you have in mind, therefore improving upon the automatically generated curve. To use a font with TEX the font metric file is required. It contains data about width, height and depth of each shape from the font. Because `mpost` could generate metric file on demand, fonts prepared with METAPOST are immediately usable with TEX.

Creation of a Type 3 font is a multi-step process.

1. A font must be imagined and designed.
2. The design must be programmed. This step is supported by a specially created library.
3. The METAPOST font program must be compiled.
4. The files thus created must be assembled into a font. This task is done by the `mkfont3` Perl script.

Additionally, the font must be made available to TEX and instructions must be given to tell TEX how to switch to this font.

Let's create a font which contain one character named plus. Use an ascii text editor — it does not have to be your favorite, any such editor works — to create a file called `plus-000.mp` that contains the following lines of text.

Each font program should name the font it creates.

```
font_name "Plus-000";
```

These names are merely comments which help to understand large collections of PostScript fonts.

```
family_name "Plus";
font_version "0.0final";
is_fixed_pitch true;
```

and following names play similar rôle in the TEX world.

```
font_identifier:="PLUS 000";
font_coding_scheme:="FONT SPECIFIC";
```

The `mpost` program does all its drawing on its internal 'graph paper'. We establish a 100 × 100 coordinate space on it.

```
grid_size:=100;
```

The font matrix array is used to map all glyphs to PostScript's 1 × 1 coordinate space. This convention allows consistent scaling of characters which come from different fonts.

```
font_matrix
  (1/grid_size,0,0,1/grid_size,0,0);
```

This particular font matrix will scale a plus shape by the factor 1/100 in the x dimensions and by the same factor in the y dimension. If we had choosen scaling by the factor 1/50 then the plus shape would have appeared twice as large as characters from other fonts.

The data below provides information about how to typeset with this font. A font quad is the unit of measure that a TEX user calls one '`em`' when this font is selected. The normal space, stretch, and shrink parameters define the interword spacing when text is being typeset in this font. A font like this is hardly ever used to typeset anything apart from the plus, but the spacing parameters have been included just in case somebody wants to typeset several pluses separated by quads or spaces.

```
font_quad:=100;
font_normal_space:=33;
font_normal_stretch:=17;
font_normal_shrink:=11;
```

Another, more or less ad hoc, unit of measure is `x_height`. In TEX this unit is available under the name '`ex`'. It it used for vertical measurements that depend on the current font, for example for accent positioning.

```
font_x_height:=100;
```

The plus font is an example of a parameterized font. A single program like this could be used to produce infinite variations of one design. For example, by changing the parameters below we could make the plus character paint in a different color, or make it thicker.

```
color plus_color;
plus_color:=red;
u:=1; % unit width
pen_width:=10;
```

The `mode_setup` macro could be used to override all the settings done above. Typically, it is used to tell the `mpost` program to generate a font metric file or proofsheets. Additionally, `mode_setup` could execute any piece of valid METAPOST code at this point. For example, we could change the color of plus to yellow and the pen width to 5 units. The code to be executed could be read from a separate file (see below on how to prepare and use such a file). Thus we can make a variation of this design or *re-parameterize* the font without changing the master `plus-000.mp` file. Such a mechanism is required, to avoid populating our hard disks with similar files.

```
mode_setup;
```

The Type3 library makes it convenient to define glyphs by starting each one with:

beginpic (⟨code⟩, ⟨width⟩, ⟨height⟩, ⟨depth⟩)

where ⟨code⟩ is either a quoted single character like `"+"` or a number that represents the glyph position in the font. The other three numbers say how the big the glyph bounding box is. The command **endpic** finishes the plus glyph.

Each **beginpic** operation assigns values to special variables called `w`, `h`, and `d`, which represent respective width, height, and depth of the current glyph bounding box. Other pseudo-words are part of METAPOST language and are explained in [6].

```
beginpic("+",100u,100,0); "+  plus";
  interim linecap:=butt;
  drawoptions(withcolor stem_color);
  pickup pencircle scaled stem_width;
  draw (w/2,-d)--(w/2,h);
  draw (0,(h-d)/2)--(w,(h-d)/2);
endpic;
```

Finally, each font program should end with the **endfont** command.

```
endfont
```

Now, we are ready to compile the font with `mpost` and assemble generated glyphs into Type 3 font with one command:

```
mkfont3 plus-000
```

To use `Plus-000` font in a TEX document it suffices to insert these lines:*

```
\font\X=plus-000 at 10pt
\centerline{\X +\quad+ +++ +\quad+}
```

This code produces the seven red pluses below.

+ +++++ +

A font cannot be proved faultless. If some glyphs are defective, the best way to correct them is to look at a big hardcopy proof that shows what went wrong. The hardcopy for the `Plus-000` font could be generated with the following shell command:

```
mkproof3 -u plus-000.map plus-000.mp
```

* To see characters from a PostScript `Plus-000` font, the DVI file must be processed by DVIPS (see the explanations at the end of this section).

As mentioned above, it is not wise to make one-time-only variation of a font by changing the font source. To change font parameters `mode_setup` is used in conjuction with the `change_mode` macro. used. I will explain this last sentence with an example.

Assume that fictitious document `doc.tex` uses `Plus-000` font and the font program reside in the file `plus-000.mp`.

The default color of the plus symbol is red. To create a variation of the font with the plus symbol painted in yellow we re-parameterize it using a file named `doc.mp`, with the following content:

```
mode_def plus_yellow = message "yellow +";
  final_; % create metric file
  font_name "Plus-b00";
  plus_color:=(1,1,0);
enddef;
```

Now, we can create a TFM file, Type 3 font, and dvips fontmap file with the command:

```
mkfont3 --change-mode=doc,plus_yellow \
  --change-name=plus-b00 plus-000.mp
```

To test the font, create a file named `doc.tex` with the following content:

```
\font\Y=plus-b00 at 10pt
\centerline{\Y +\quad+ +++ +\quad+}
```

typeset it and convert to PostScript:

```
tex doc.tex
dvips -u plus-b00.map doc.dvi -o doc.ps
```

This should generate file named `doc.ps` which may be viewed and printed, for example with the Ghostscript program. The programmed yellow plus is printed below.

+ +++++ +

Generating hardcopy proofs, compiling fonts, typesetting documents requires remembering and executing a lot of shell commands. Here, the `make` utility helps a lot [20].

Type 1 font example

Type 1 font programming differs from Type 3 font programming. Type 3 glyphs can use any PostScript command, but Type 1 glyphs use a subset of PostScript. Moreover, we must construct an outline of glyph instead of drawing it. The outline is filled when the glyph is printed.

Each METAPOST font should input the METAPOST Type1 library. The library contains macros which help to compute outlines, and to output various font data to several files. These data are used by the mkfont1 script which assembles Type 1 font and mkproof1 script which typesets hardcopy proofs.

The Type 1 font programmed below contains nothing but a plus symbol. Let's start with reading basic macros.

```
input type1;
```

Next follows the usual font administration stuff. Each font should define several variables [9, Tables 5.1–4].

```
pf_info_familyname "Plus";
pf_info_fontname "Plus-Regular";
pf_info_weight "Normal";
pf_info_version "1.0";
pf_info_fixedpitch true;
pf_info_author "Anonymous 2002";
pf_info_creationdate;
```

The mpost program does all its drawing on its internal 'graph paper' with 1000×1000 coordinate space on it. The data below provides information about how to typeset with this font.

```
pf_info_quad 760;
pf_info_capheight 760;
pf_info_xheight 760;
pf_info_space 333;
```

The adl suffix here is a mnemonic for *Ascender*, *Descender*, and *Lineskip*.

```
pf_info_adl 750, 250, 0;
```

The PostScript **fill** operator is used to paint the entire region closed by the current path. For each path, the *non-zero winding number rule* [9, p. 161] determines whether a given point is inside a path. This behaviour is simulated by the Fill and unFill macros. The fill_outline macro, for each closed path stored in the array s[1..s.num], fills or unfills it based on its *turning number* [4, p. 111].

```
def fill_outline suffix s =
  for i:=1 upto s.num:
    if turningnumber s[i] > 0: Fill
    else: unFill fi s[i];
  endfor
enddef;
```

The plus sign has squared-off ends. Macro butt_end simplifies the task of cutting of ends of paths.

```
def butt_end(text nodes) =
  cut(rel 90)(nodes)
enddef;
```

A horizontal line of the same width as a vertical line seems thicker. To avoid this optical illusion we use an elliptical pen.

```
numeric px; px:=100;
numeric py; py:=90;
default_nib:=fix_nib(px,py,0);
```

These names are intended to make the code more readable.

```
path vertical_stem, horizontal_stem;
path glyph;
```

Each glyph should be defined within a block defined by beginfont and endfont commands.

```
beginfont
```

Programmed symbols must be given names as well as positions in the font.

```
encode("plus",43);
```

Each glyph starts with **beginglyph** and ends with **endglyph** macro. The following macros initialize several variables, used for the glyph data bookkeeping.

```
standard_introduce("plus");
beginglyph("plus");
```

For convenience, the width, height and depth of the character are assigned to variables w, h, and d.

```
w:=760; h:=760; d:=0;
```

The horizontal and vertical bars of the plus glyph are centered with respect its bounding box.

```
z0=(w/2,d); z1=(w/2,h);
z2=(0,(h-d)/2); z3=(w,(h-d)/2);
```

To draw paths z0--z1 and z2--z3 the pen with a default_nib-shaped nib is used. The macro pen_stroke finds the outline of each path. Outlines are assigned to the paths vertical_stem and horizontal_stem. The macro butt_end cuts off the ends of these paths at times 0 (beginning) and 1 (end).

```
pen_stroke(butt_end(0,1))(z0--z1)
  (vertical_stem);
pen_stroke(butt_end(0,1))(z2--z3)
  (horizontal_stem);
```

Programming a Type 1 glyph means constructing its outline (which could be made up of several cyclic paths). The macro below finds the outline of the paths constructed above and stores it in the array named in the second argument.

```
find_outlines
  (vertical_stem,horizontal_stem)(glyph);
```

Now, we are ready to draw the plus symbol.

```
fill_outline glyph;
```

Finally, we fix the width of the glyph to w and its left and right sidebearings to 0.

```
fix_hsbw(w,0,0);
```

Each symbol should include so-called *hints* [8, p. 56–57] that make it render better on a wide variety of devices.

```
fix_hstem(py)(horizontal_stem);
fix_vstem(px)(vertical_stem);
```

To make our hardcopy proofs more readable we define some construction points (see the figure below).

```
dotlabels(0,1,2,3);
```

The last two macros end the subprogram for plus symbol and the whole font program.

```
endglyph;
endfont;
```

Now, we can create a TFM file, Type 1 font, and dvips fontmap file with the command:

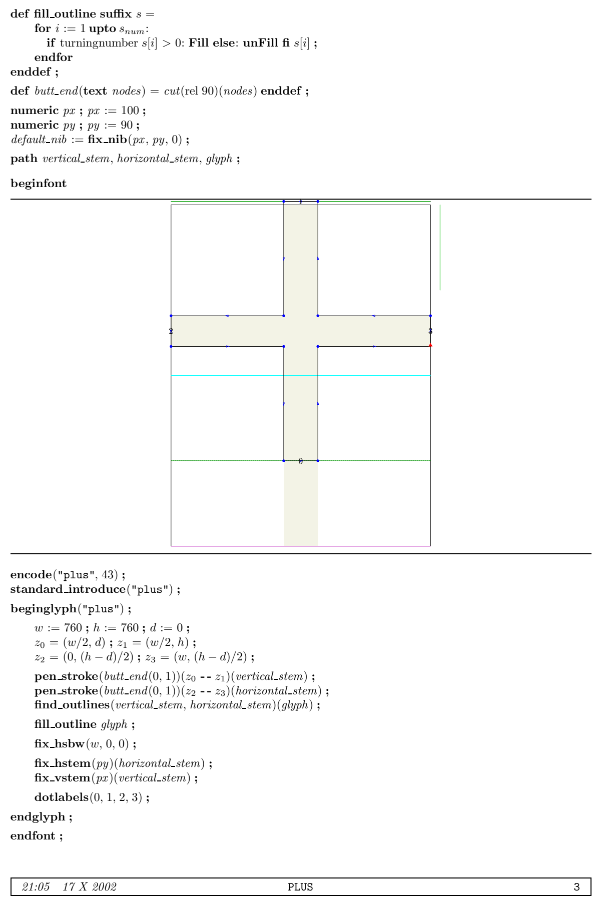
```
mkfont1 plus.mp
```

The plus character just constructed is used to print the divider line below.

+ ++++ + +

The hardcopy proof below was typeset with the command:

```
mkproof1 -u plus.map plus.mp
```



```
def fill_outline suffix s =
    for i := 1 upto s_num:
      if turningnumber s[i] > 0: Fill else: unFill fi s[i] ;
    endfor
enddef ;
def butt_end(text nodes) = cut(rel 90)(nodes) enddef ;
numeric px ; px := 100 ;
numeric py ; py := 90 ;
default_nib := fix_nib(px, py, 0) ;
path vertical_stem, horizontal_stem, glyph ;
beginfont
```

```
encode("plus", 43) ;
standard_introduce("plus") ;
beginglyph("plus") ;
    w := 760 ; h := 760 ; d := 0 ;
    z0 = (w/2, d) ; z1 = (w/2, h) ;
    z2 = (0, (h - d)/2) ; z3 = (w, (h - d)/2) ;
    pen_stroke(butt_end(0, 1))(z0 -- z1)(vertical_stem) ;
    pen_stroke(butt_end(0, 1))(z2 -- z3)(horizontal_stem) ;
    find_outlines(vertical_stem, horizontal_stem)(glyph) ;
    fill_outline glyph ;
    fix_hsbw(w, 0, 0) ;
    fix_hstem(py)(horizontal_stem) ;
    fix_vstem(px)(vertical_stem) ;
    dotlabels(0, 1, 2, 3) ;
endglyph ;
endfont ;
```

21:05 17 X 2002 PLUS 3

Appendix

This description is somewhat simplified in respect to the examples to be found in [6, 9].

Each Type 3 font should begin with two lines of comments.

```
%!PS-AdobeFont-1.0: Square 1.00
%%CreationDate: 1 May 2001
```

A Type 3 font consists of a single dictionary, possibly containing other dictionaries, with certain required entries. The dictionary of size 99 should suffice for fonts which consists of several characters.

```
99 dict begin
```

This dictionary should include following entries:

- Variable `FontType` indicates how the character information is organized; for Type 3 fonts it has to be set 3.
- Variable `LanguageLevel` is set to the minimum PostScript language level required for correct behavior of the font.
- Array `FontMatrix` transforms the character coordinate system into the user coordinate system. This matrix maps font characters to one-unit coordinate space, which enables the PostScript interpreter to scale font characters properly. This font uses a 1000-unit grid.
- Array (of four numbers) `FontBBox` gives lower-left (l_x, l_y) and upper-right (u_x, u_y) coordinates of the smallest rectangle enclosing the shape that would result if all characters of the font were placed with their origins coincident, and then painted. This information is used in making decisions about character caching and clipping. If all four values are zero, no assumptions about character bounding box are made.

```
/FontType 3 def
/LanguageLevel 2 def
/FontMatrix [ 0.001 0 0 0.001 0 0 ] def
/FontBBox [ 0 0 1000 1000] def
```

The `FontInfo` dictionary is optional. All information stored there is entirely for the benefit of PostScript language programs using the font, or for documentation.

- `FamilyName` — a human readable name for a group of fonts. All fonts that are members of such a group should have exactly the same FamilyName.
- `FullName` — unique, human readable name for an individual font. Should be the same name as one used when registering the font with the `definefont` operator below.
- `Notice` — copyright, if applicable.

- `Weight` — name for the "boldness" attribute of a font.
- `version` — version number of the font program.
- `ItalicAngle` — angle in degrees counterclockwise from the vertical of the dominant vertical strokes of the font.
- `isFixedPitch` — if true, indicates that the font is a monospaced font; otherwise set false.
- `UnderlinePosition` — recommended distance from the baseline for positioning underlining strokes (y coordinate).
- `UnderlineThickness` — recommended stroke width for underlining, in units of the character coordinate system.

```
/FontInfo <<
   /FamilyName (Geometric)
   /FullName (Square)
   /Notice (Type 3 Repository.
     Copyright \(C\) 2001 Anonymous.
     All Rights Reserved.)
   /Weight (Medium)
   /version (1.0)
   /ItalicAngle 0
   /isFixedPitch true
   /UnderlinePosition 0.0
   /UnderlineThickness 1.0
>> def
```

The `Encoding` array maps character codes (integers) to character names. All unused positions in the encoding vector must be filled with the name `.notdef`. It is special in only one regard: if some encoding maps to a character name that does not exist in the font, `.notdef` is substituted. The effect produced by executing `.notdef` character is at the discretion of the font designer, but most often it is the same as space.

```
/Encoding 256 array def
0 1 255
  {Encoding exch /.notdef put}
for
```

The `CharacterProcedures` dictionary contains individual character definitions. The name is not special — any name could be used — but this name is assumed by the `BuildGlyph` procedure below.

```
/CharacterProcedures 256 dict def
```

Each character must invoke one of the `setcachedevice` and `setcharwidth` operators before executing graphics operators to define and paint the character. The `setcachedevice` operator stores the bitmapped image of the character in the font cache. However, caching will not work if color or gray is used. In such cases the `setcharwidth` operator should be used, which is similar to `setcachedevice`, but declares that the character being defined is not to be placed in the font cache.

w_x w_y l_x l_y u_x u_y `setcachedevice` –

w_x, w_y — comprise the basic width vector, i.e., the normal position of the origin of the next character relative to origin of this one

l_x, l_y, u_x, u_y — are the coordinates of this character bounding box

w_x w_y `setcharwidth` –

w_x w_y — comprise the basic width vector of this character

```
CharacterProcedures /.notdef {
   1000 0 0 0 1000 1000 setcachedevice
   1000 0 moveto
} put
Encoding 32 /space put
CharacterProcedures /space {
   1000 0 0 0 1000 1000 setcachedevice
   1000 0 moveto
} put
Encoding 83 /square put % ASCII ‘S’
CharacterProcedures /square {
   1000 0 setcharwidth
   0 1 1 0 setcmykcolor % red
   0 0 1000 1000 rectfill
} put
```

The `BuildGlyph` procedure is called within the confines of a `gsave` and a `grestore`, so any changes `BuildGlyph` makes to the graphics state do not persist after it finishes.

`BuildGlyph` should describe the character in terms of absolute coordinates in the character coordinate system, placing the character origin at $(0, 0)$ in this space.

The Current Transformation Matrix (CTM) and the graphics state are inherited from the environment. To ensure predictable results despite font caching, `BuildGlyph` must initialize any graphics state parameter on which it depends. In particular, if `BuildGlyph` executes the `stroke` operator, it should explicitly set: dash parameters, line cap, line join, line width. These initializations are unnecessary if characters are not cached, for example if the `setcachedevice` operator is not used.

When a PostScript language interpreter tries to show a character from a font, and the character is not already present in the font cache it pushes *current font dictionary* and *character name* onto the operand stack. The `BuildGlyph` procedure must remove these two objects from the operand stack and use this information to render the requested character. This typically involves finding the character procedure and executing it.

```
/BuildGlyph { % stack: font charname
  exch
  begin
  % initialize graphics state parameters
  % turn dashing off: solid lines
    [ ] 0 setdash
  % projecting square cap
    2 setlinecap
  % miter join
    0 setlinejoin
  % thickness of lines rendered by
  % execution of the stroke operator
    50 setlinewidth
  % the miter limit controls the stroke
  % operator's treatment of corners;
  % this is the default value and it
  % causes cuts off mitters at
  % angles less than 11 degrees
    10 setmiterlimit
    CharacterProcedures exch get exec
  end
} bind def
currentdict
end % of font dictionary
```

Finally, we register the font name as a font dictionary defined above and associate it with the key `Square`. Additionally the `definefont` operator checks if the font dictionary is a well-formed.

```
/Square exch definefont pop
```

If the following lines are not commented out the Ghostscript program (a public domain PostScript interpreter) will show the text below online. Obviously, these lines should be commented out in the final version of the font program.

```
/Square findfont
  72 scalefont setfont
0 72 moveto (S) show
showpage
```

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