

32 YEARS OF

METAFONT

VELLOW

# The METAFONTbook

DONALD E. KNUTH

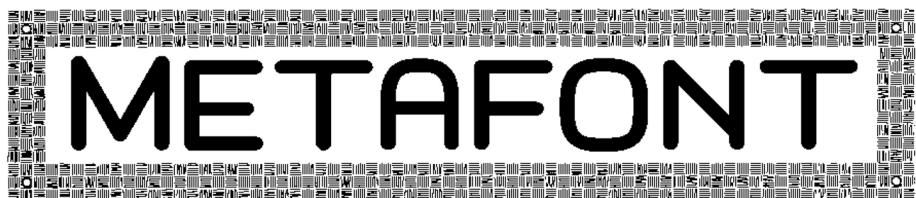


400-

FONT

FONT BLDG

FOONIT



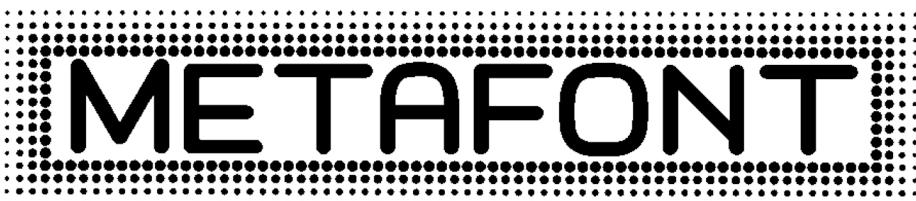
Don Knuth



Ann Lasko-Harvill



Bruce Leban



Dan Mills



Arnie Olds



400 -  
FONT



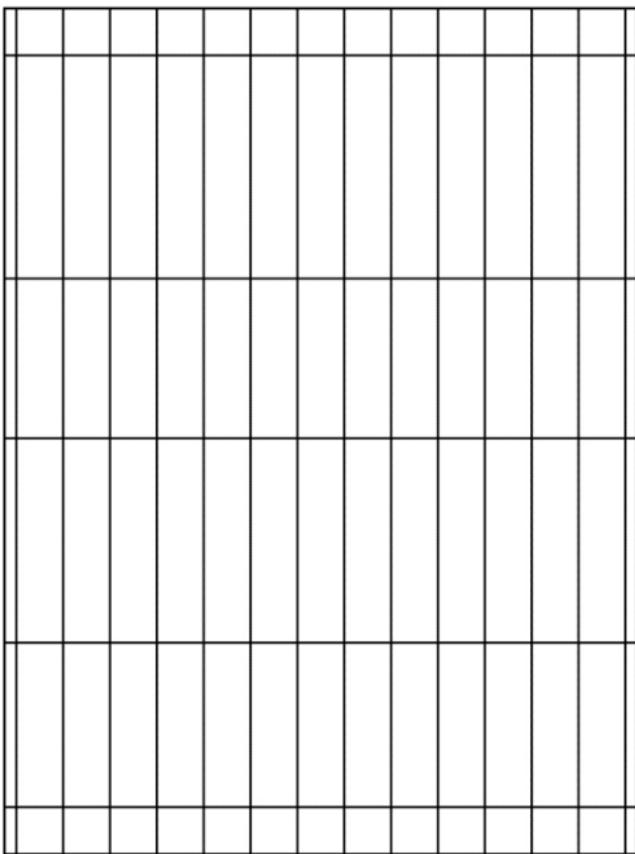
400-  
**FONT**

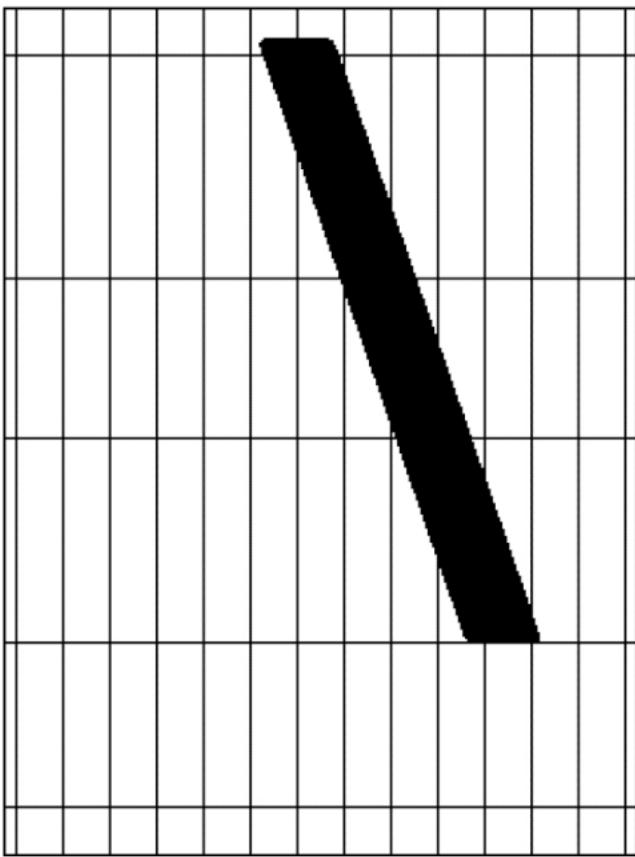


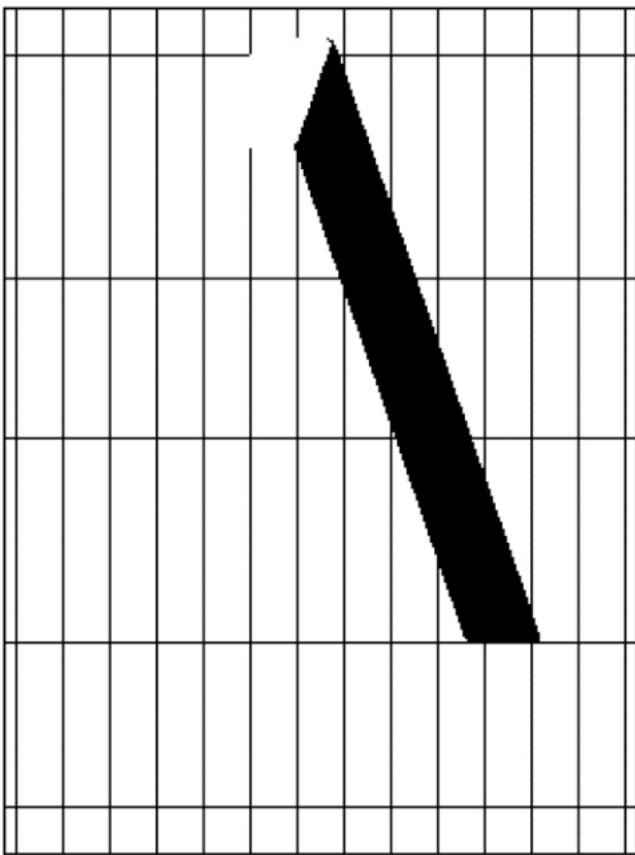
# *Digital Typography*

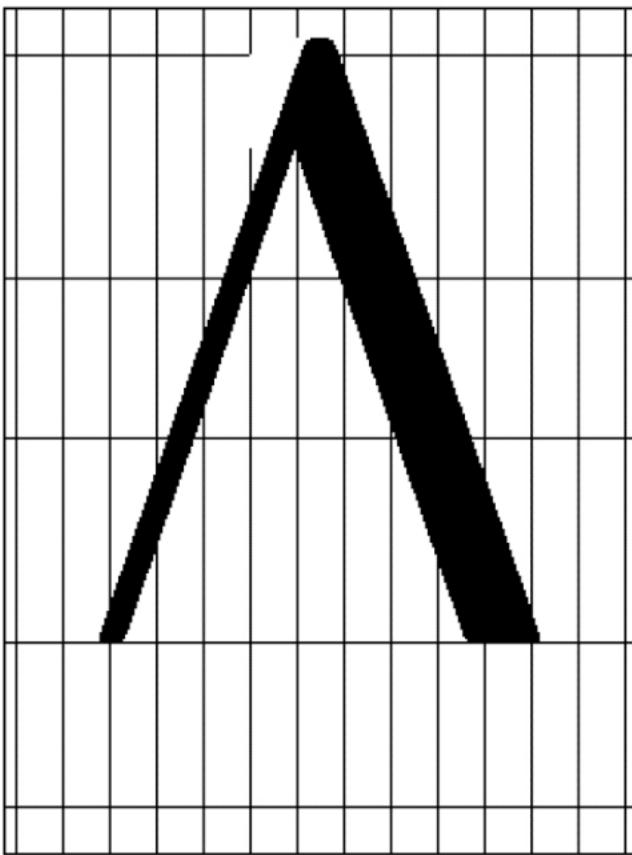


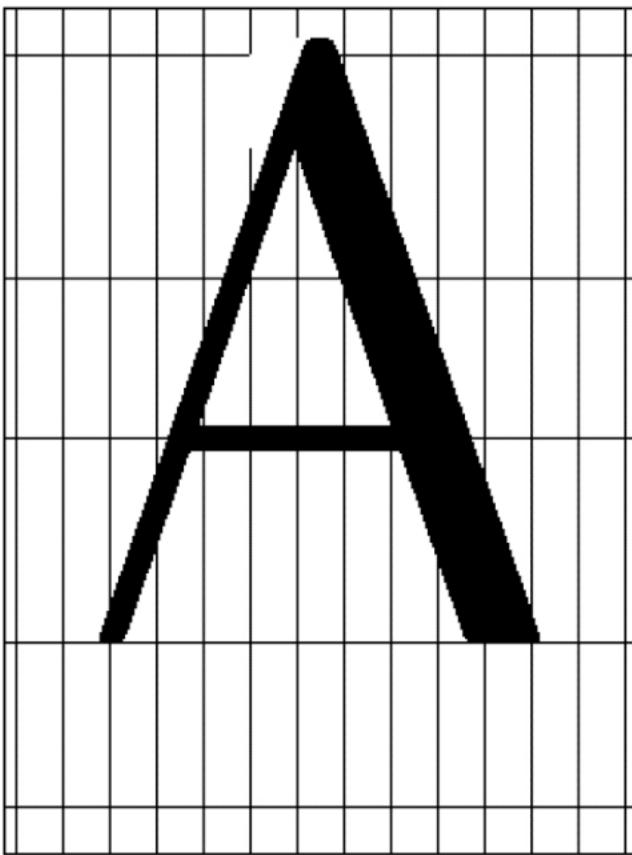
Donald E. Knuth

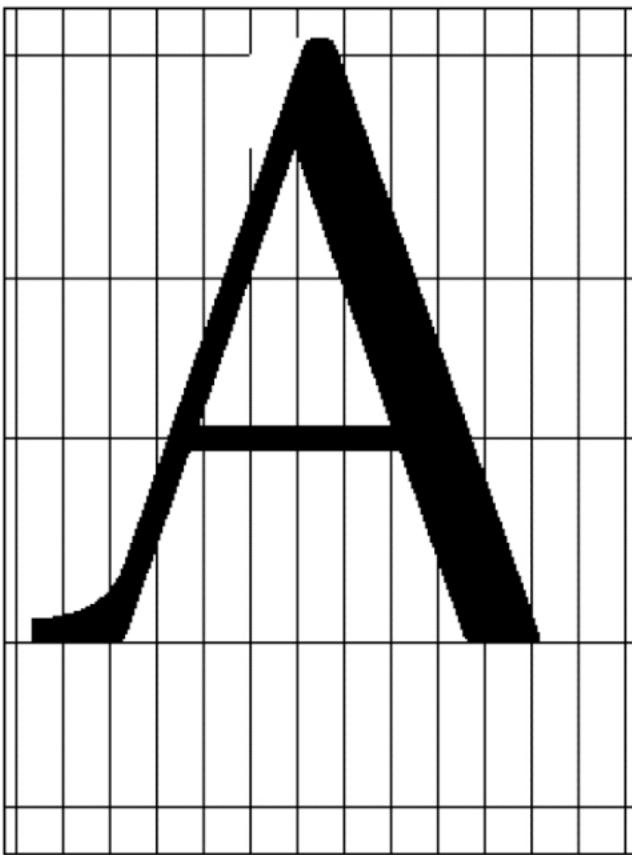


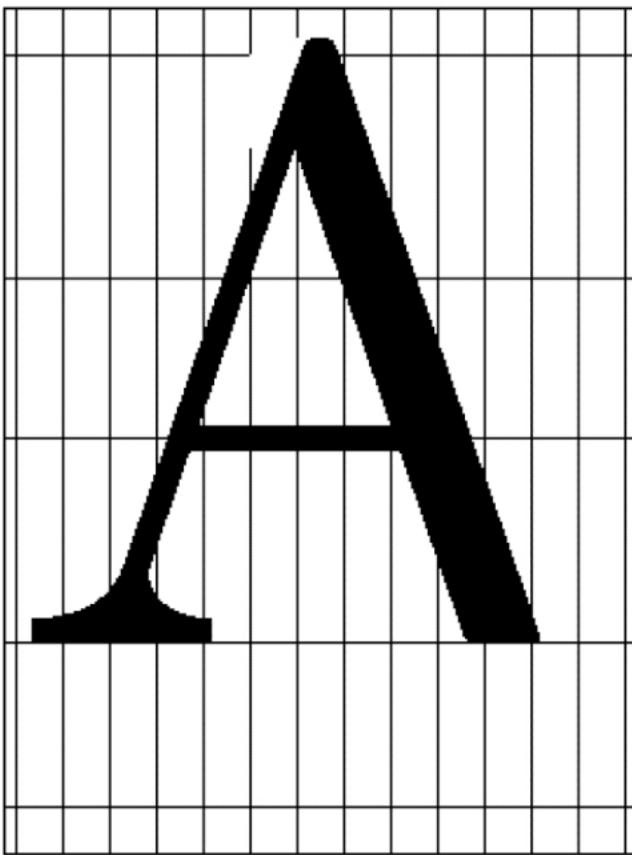


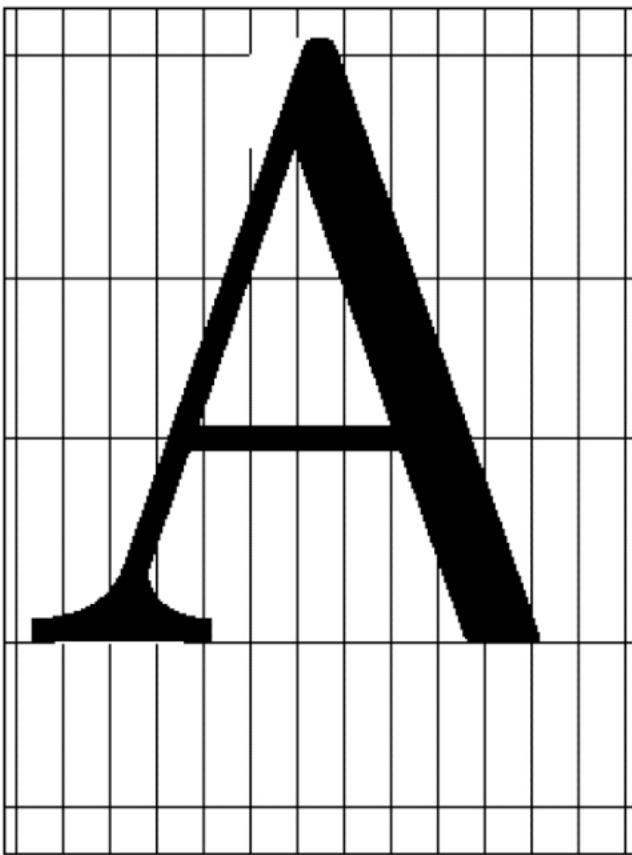


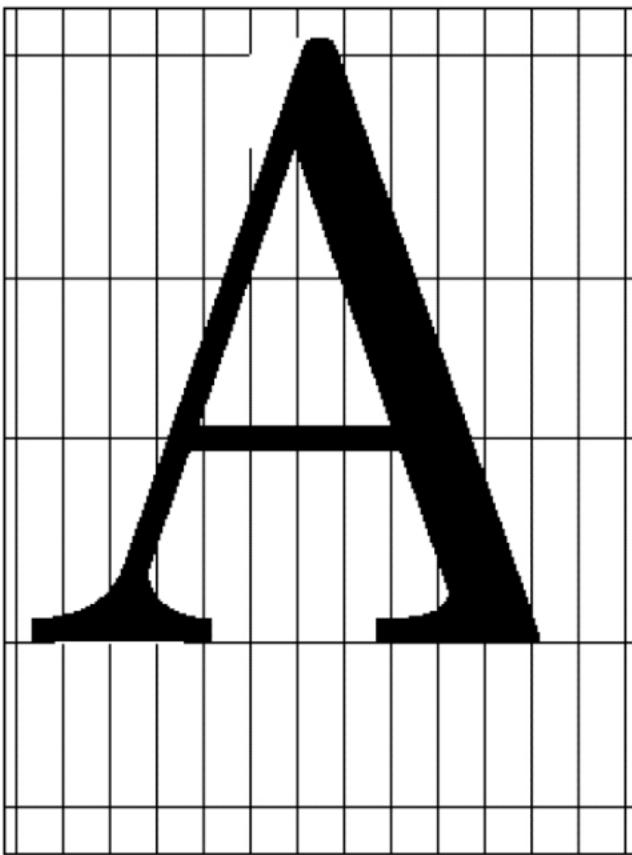


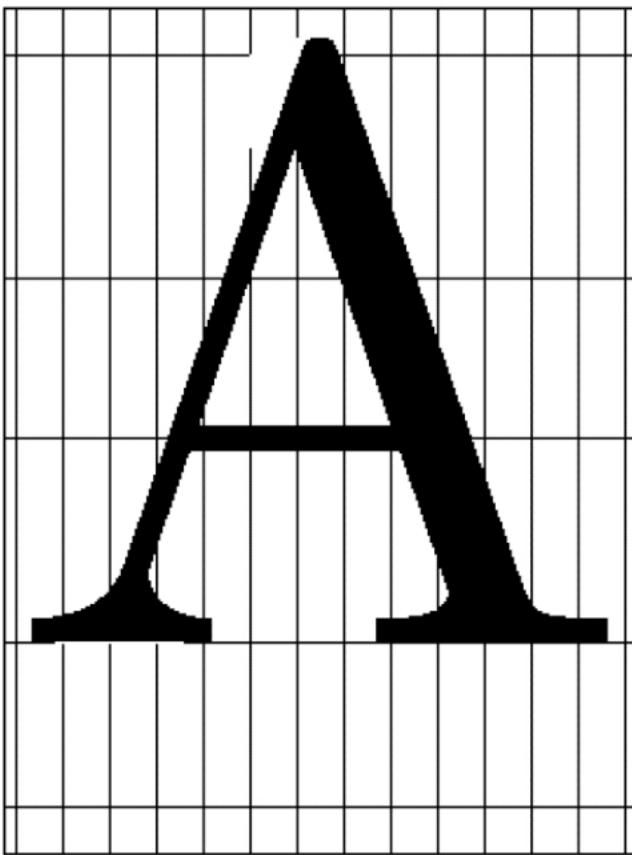


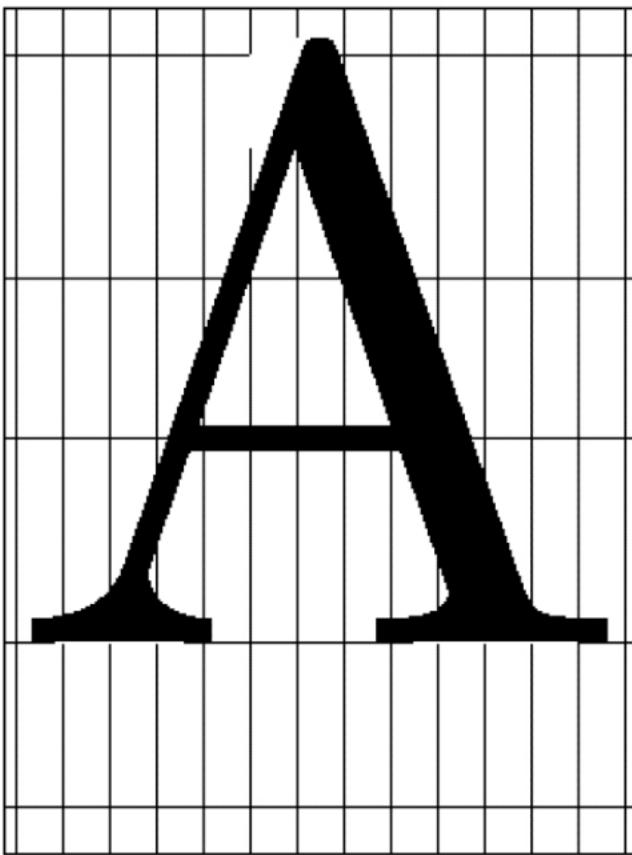












N

N

N

A

A

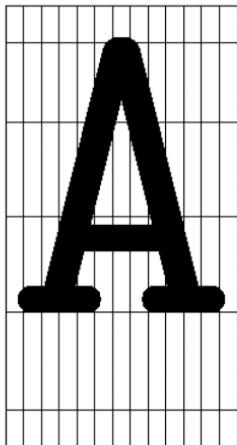
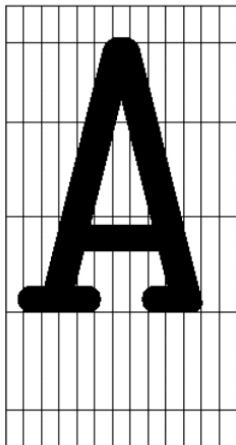
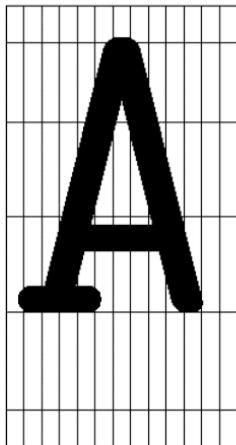
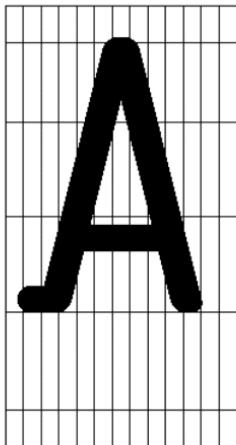
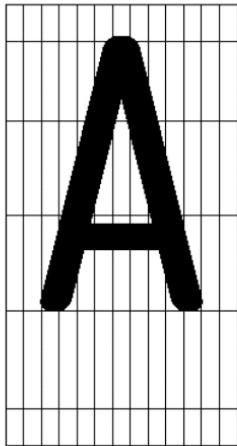
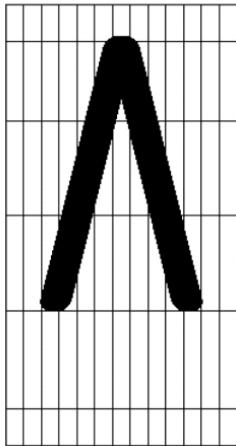
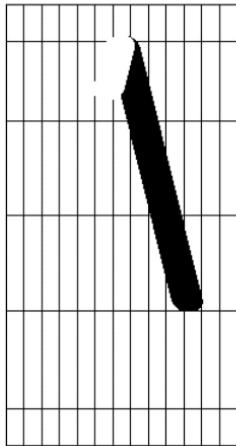
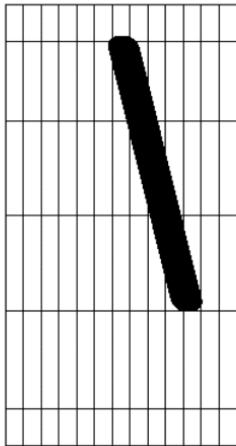
A

A

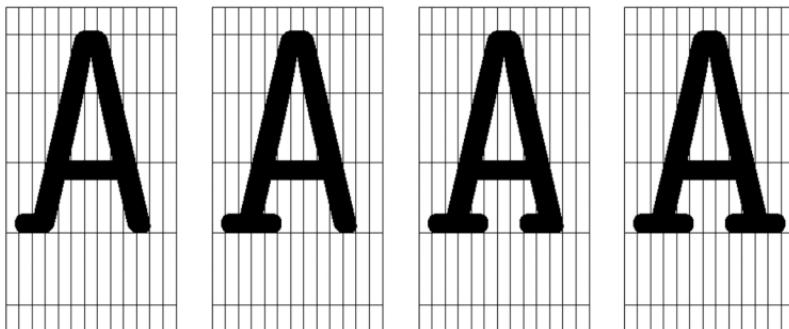
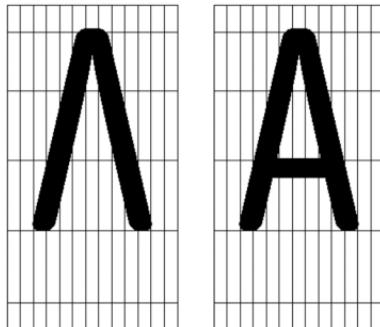
A

A

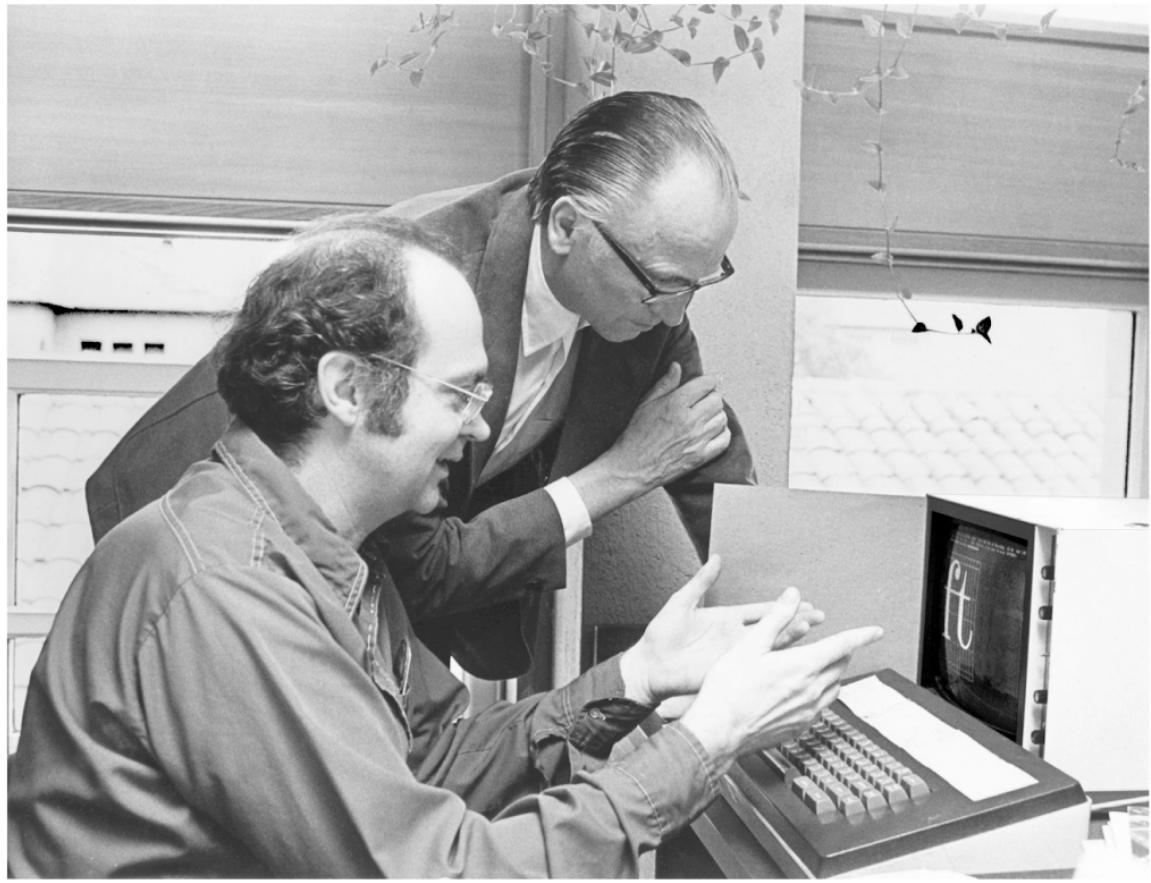
A



The resulting A went into my first typewriter-style font, but I learned later that such an A was a bit darker than it should be. To solve the problem, I moved the two diagonal strokes slightly apart, and cut a “notch” in the interior so as to open the inside a bit.



This is the nice typewriter-style A that I use today. I didn't learn such tricks until several years after I started to study type design.



The first collaboration between DEK (seated) and HZ (standing), 14 February 1980. [Stanford News Service photo by Chuck Painter.]

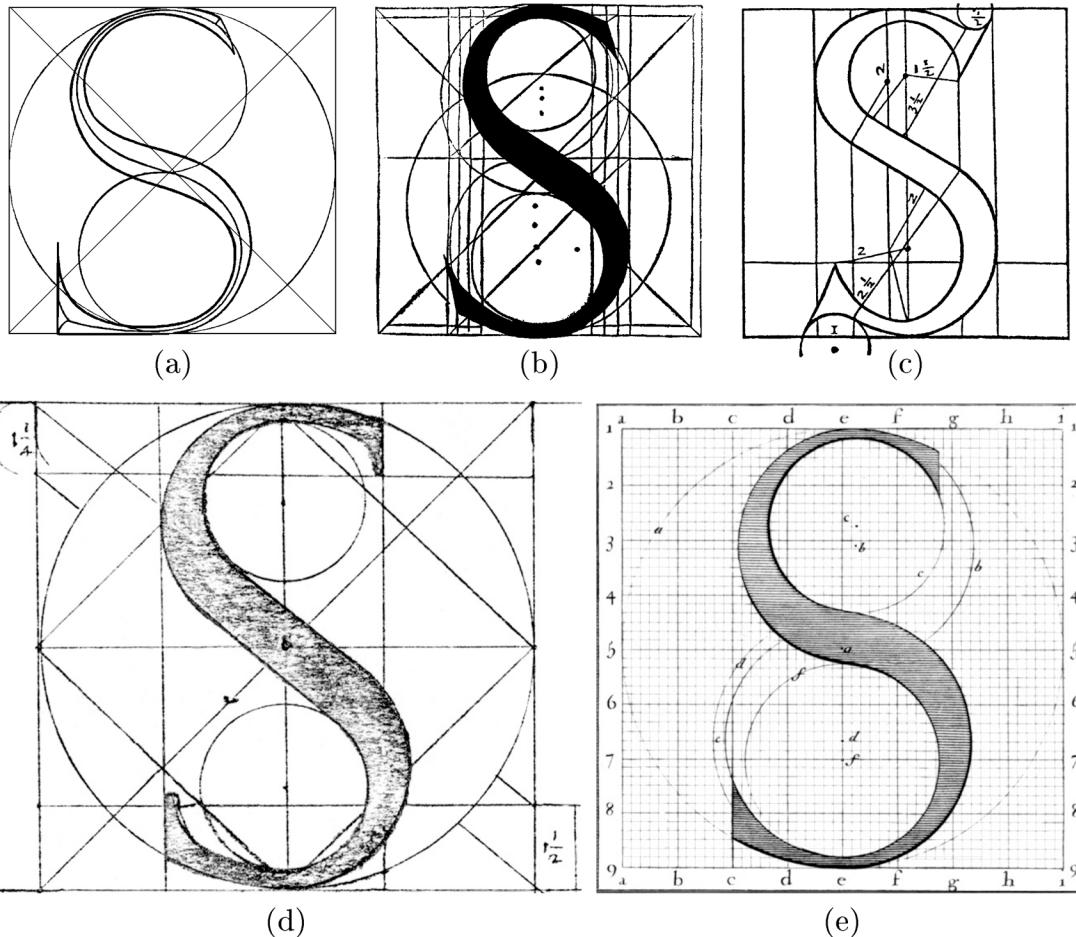


FIGURE 11. The letter S as defined by (a) Feliciano [19]; (b) Pacioli [43]; (c) Torniello [34]; (d) Palatino [44]; (e) French commission under Jaugeon [24].

g g g g g g g g



FIGURE 12.

Another example of interdependence appears in Figure 12; again a series of letters has been drawn with only one parameter of the program changing. In the upper line I changed the slope at the middle of the S; in the lower line I changed the weight. In both cases a number of points changed their position in order to accommodate other changes, because I defined the positions by formulas instead of using numbers.

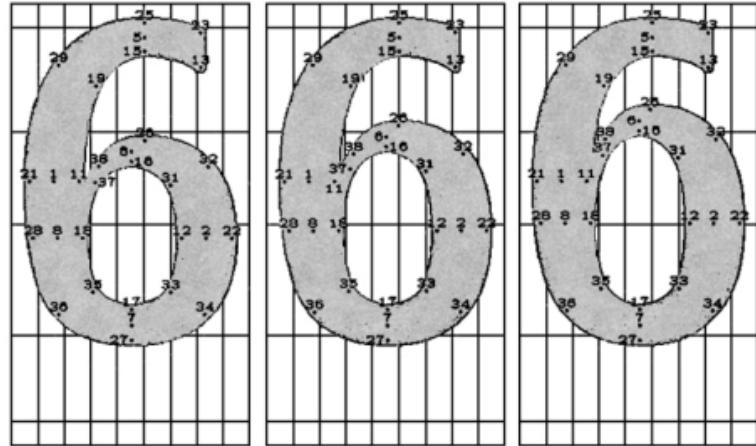


FIGURE 11.

Figure 11 exhibits a similar dependence; I made these three '6's by varying the position of only one point in the specification (point 6, which is at the top of the bowl). Many of the other points changed their position when point 6 moved, because my METAFONT program specified their positions relative to other points rather than with absolute coordinates.

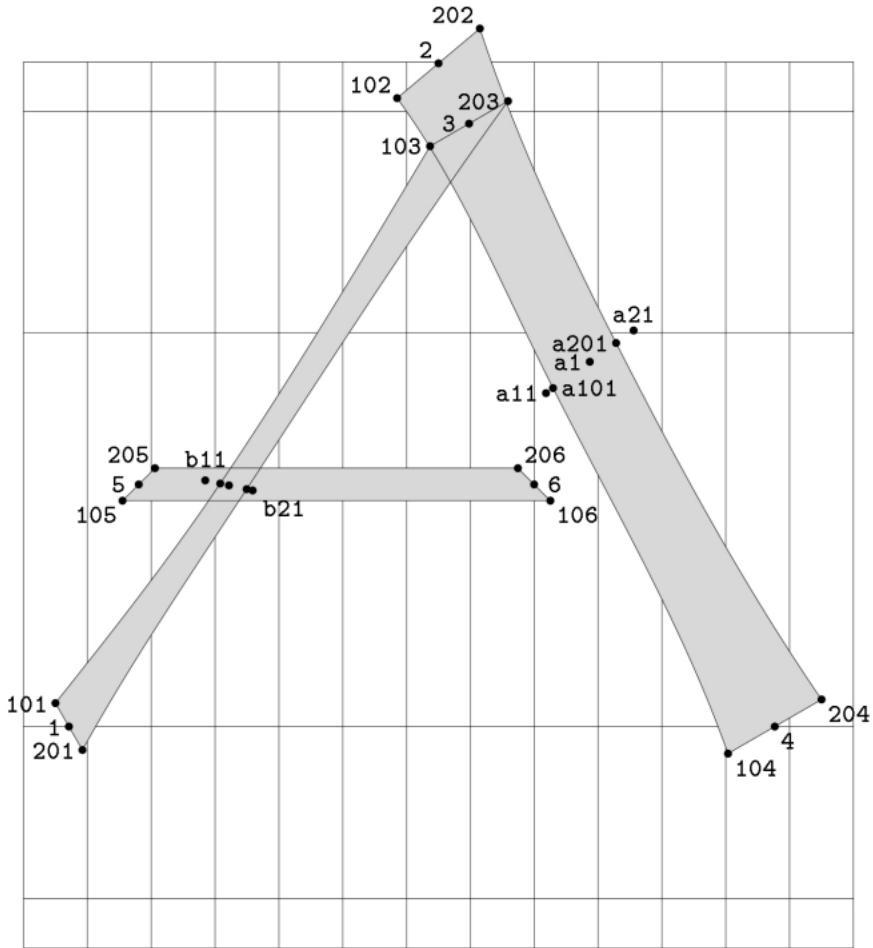
A

T

Y

P

L



AAA AAA AAA

AAA AAA AAA

AAA AAA AAA

```

% Sumner Stone's A for ATypI, cut for METAFONT84 by Don Knuth

mode_setup;
# := 26/36pt#; % basic unit
cap_height# := 245/36pt#; % height of uppercase
thin# := 22/36pt#; % weight of thin strokes
thick# := 44/36pt#; % weight of thick strokes
tau := 0.4; % typical amount of tapering
gap := 1; % units of stroke separation
cut := 15; % degrees of tilt at stroke edge
aspect := 0.85; % vertical / horizontal weight ratio

define_pixels(u);
define_blackter_pixels(thin, thick);

vardef penpos@#(expr angle, d) = % set pen position
  z@# = .5[z@#l, z@#r]; z@#r - z@#l = (d, 0) rotated angle;
enddef;

vardef stroke(suffix $, $$, @)(expr lambda, rho, alpha) = % tapered stroke
  z@ = alpha[z$, z$$]; z@l = alpha[z$l, z$$l]; z@r = alpha[z$r, z$$r];
  z@l' = lambda[z@l, z@]; z@r' = rho[z@r, z@]; % pull in for tapering
  labels(@, @l, @r, @l', @r');
  z$1{z@ - z$1} .. z@l'{z$$l - z$1} .. z$$l{z$$l - z@} --
  z$$r{z@ - z$$r} .. z@r'{z$r - z$$r} .. z$r{z$r - z@} -- cycle
enddef;

"The letter A";
beginchar("A", 13#, 1.1cap-height#, 0);
  penpos1(-cut - 45, thin);
  penpos2(cut + 25, thick);
  penpos3(cut + 15, 2/3[thin, thick]);
  penpos4(cut + 15, thick);
  penpos5(45, aspect * thin);
  penpos6(135, aspect * thin);
  y1 = 0; x1l = .5u;
  y4 = 0; x4r = w - .5u;
  y2 = 1.1h; x2 = .5w;
  y3 = h; z3 = whatever[z2, z4];
  y5r = 3/7h; z5 + (gap * u + .5thin, 0) = whatever[z1, z3];
  y6r = 3/7h; z6 + (gap * u + .5thick, 0) = whatever[z2, z4];
  fill stroke(3, 1, b, sqrt tau, tau * sqrt tau, .6); % left diagonal
  unfill z2 -- z4 -- (z4 + (thick, 0)) -- (z2 + (thick, 0)) -- cycle; % erase excess
  cullit; % normalize after erasing
  fill stroke(2, 4, a, tau * tau, tau, .45); % right diagonal
  fill z5l -- z6l -- z6r -- z5r -- cycle; % bar line
  penlabels(range 1 thru 6); endchar;
end.

```

```
% Routines for the METAFONT logo, as found in The METAFONTbook
% (logo10.mf is a typical parameter file)

mode_setup;
if unknown slant: slant:=0 else: currenttransform:=
  identity slanted slant yscaled aspect_ratio fi;

ygap#:=(ht#/13.5u#)*xgap#;                                % vertical adjustment
hof:=of#;                                                 % horizontal overshoot
leftstemloc#:=2.5u#+s#;                                    % position of left stem
barheight#:=.45ht#;                                         % height of bar lines
py#:=.9px#;                                                 % vertical pen thickness

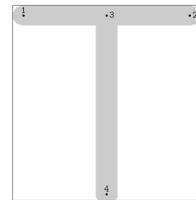
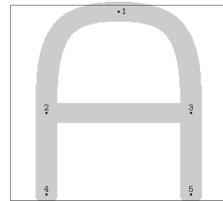
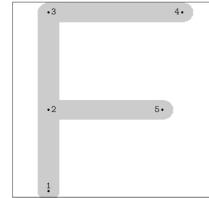
define_pixels(s,u);
define_whole_pixels(xgap);
define_whole_vertical_pixels(ygap);
define_blackter_pixels(px,py);
pickup pencircle xscaled px yscaled py;
logo_pen:=saveopen;
define_good_x_pixels(leftstemloc);
define_good_y_pixels(barheight);
define_corrected_pixels(o);
define_horizontal_corrected_pixels(ho);

def beginlogochar(expr code, unit_width) =
  beginchar(code,unit_width*u#+2s#,ht#,0);
  pickup logo_pen enddef;

def super_half(suffix i,j,k) =
  draw z.i{0,y.j-y.i}
  ... (.8[x.j,x.i],.8[y.i,y.j]) {z.j-z.i}
  ... z.j{x.k-x.i,0}
  ... (.8[x.j,x.k],.8[y.k,y.j]) {z.k-z.j}
  ... z.k{o,y.k-y.j} enddef;

beginlogochar("M",18);
x1=x2=leftstemloc; x4=x5=w-x1; x3=w-x3;
y1=y5; y2=y4; bot y1=-o;
top y2=h+o; y3=y1+ygap;
draw z1--z2--z3--z4--z5;
labels(1,2,3,4,5); endchar;

beginlogochar("E",14);
x1=x2=x3=leftstemloc;
x4=x6=w-x1+ho; x5=x4-xgap;
y1=y6; y2=y5; y3=y4;
bot y1=0; top y3=h; y2=barheight;
```



```

draw z6--z1--z3--z4; draw z2--z5;
labels(1,2,3,4,5,6); endchar;

beginlogochar("T",13);
italcorr ht#*slant + .5u#;
if .5w<>good.x .5w: change_width; fi
lft x1=-eps; x2=w-x1; x3=x4=.5w;
y1=y2=y3; top y1=h; bot y4=-o;
draw z1--z2; draw z3--z4;
labels(1,2,3,4); endchar;

beginlogochar("A",15);
x1=.5w; x2=x4=leftstemloc; x3=x5=w-x2;
top y1=h+o; y2=y3=barheight;
bot y4=bot y5=-o;
draw z4--z2--z3--z5; super_half(2,1,3);
labels(1,2,3,4,5); endchar;

beginlogochar("F",14);
x1=x2=x3=leftstemloc;
x4=w-x1+ho; x5=x4-xgap;
y2=y5; y3=y4; bot y1=-o;
top y3=h; y2=barheight;
draw z1--z3--z4; draw z2--z5;
labels(1,2,3,4,5); endchar;

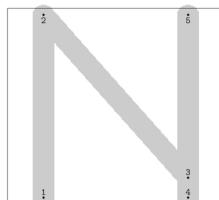
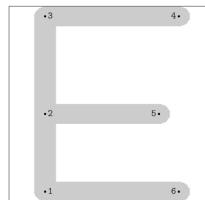
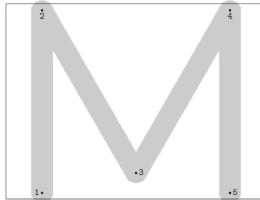
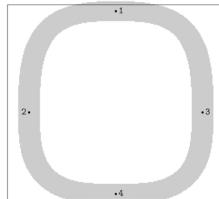
beginlogochar("O",15);
x1=x4=.5w; top y1=h+o; bot y4=-o;
x2=w-x3=good.x(1.5u+s); y2=y3=barheight;
super_half(2,1,3); super_half(2,4,3);
labels(1,2,3,4); endchar;

beginlogochar("N",15);
x1=x2=leftstemloc; x3=x4=x5=w-x1;
bot y1=bot y4=-o;
top y2=top y5=h+o; y3=y4+ygap;
draw z1--z2--z3; draw z4--z5;
labels(1,2,3,4,5); endchar;

ligtable "T": "A" kern -.5u#;
ligtable "F": "O" kern -u#;

font_quad:=18u#+2s#;
font_normal_space:=6u#+2s#;
font_normal_stretch:=3u#;
font_normal_shrink:=2u#;
font_identifier:="MFLOGO" if slant<>0: & "SL" fi;
font_coding_scheme:="AEFMNOT only";

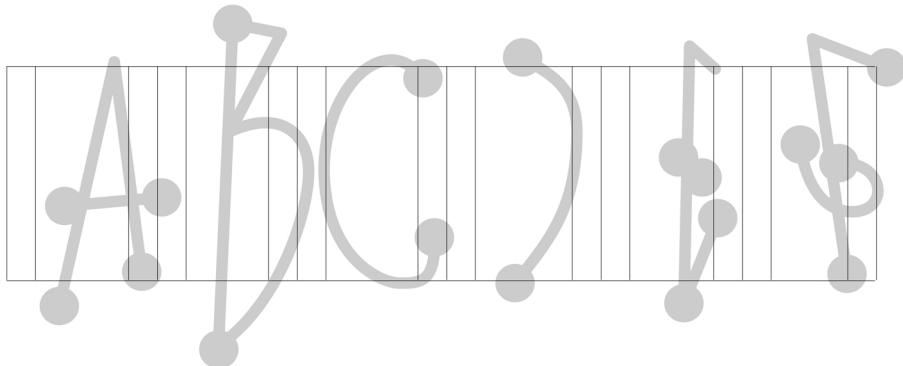
```





Of course there were bugs in my code. For example, the first few letters came out looking like this on the initial proofsheets:

METAFONT output 1985.02.28:1504



(I refuse to show you the first form of the letter 'G'.) But by 4 pm I was ready to make the first trial setting of text:

THIS 'PUNK' ALPHABET, INSPIRED BY  
MARJAN'S LECTURE LAST NIGHT, WAS  
DESIGNED BY METAFONT'S RANDOM NUM-  
BER GENERATOR. THE QUICK BROWN FOX  
JUMPED OVER THE LAZY HAMBURGERS.

PUNK12

A FORKED VEIN BEGAN TO SWELL IN SPADE'S FOREHEAD. . . . HIS VOICE BECAME PERSUASIVE AGAIN. 'LISTEN, GUTMAN, WE'VE ABSOLUTELY GOT TO GIVE THEM A VICTIM. THERE'S NO WAY OUT OF IT. LET'S GIVE THEM THE PUNK.' HE NODDED PLEASANTLY AT THE BOY IN THE DOORWAY. [2]



```

beginpunkchar("A", 13, 1, 2);
 $z_1 = pp(1.5u, 0); z_2 = (.5w, 1.1h); z_3 = pp(w - 1.5u, 0);$ 
pd  $z_1$ ; pd  $z_3$ ; draw  $z_1$  --  $z_2$  --  $z_3$ ; % left and right diagonals
 $z_4 = pp.3[z_1, z_2]; z_5 = pp.3[z_3, z_2];$ 
pd  $z_4$ ; pd  $z_5$ ; draw  $z_4$  --  $z_5$ ; % crossbar
endchar;

beginpunkchar("B", 12, 1, 1);
 $z_1 = pp(2u, 0); z_2 = pp(2u, .6h); z_3 = pp(2u, h);$ 
pd  $z_1$ ; pd  $z_3$ ; draw  $z_1$  --  $z_3$ ; % stem
 $z_{1.5} = pp(w - u, .5y_2); z_{2.5} = pp(w - u, .5[y_2, y_3]);$ 
draw  $z_2$  --  $z_{2.5}$  --  $z_3$ ; % upper lobe
draw  $flex(z_2, z_{1.5}, z_1);$  % lower lobe
endchar;

beginpunkchar("C", 13, 1, 2);
 $z_1 = pp(w - 2u, .8h); z_2 = pp(.6w, h); z_3 = pp(u, .5h);$ 
 $z_4 = (.6w, 0); z_5 = (w - 2u, .2h);$ 
pd  $z_1$ ; pd  $z_5$ ; draw  $z_1$  ..  $z_2$  ..  $z_3$  ..  $z_4$  ..  $z_5$ ; % arc
endchar;

beginpunkchar("D", 14, 1, 2);
 $z_1 = pp(2u, 0); z_2 = pp(2u, h); z_3 = pp(w - u, .6h);$ 
pd  $z_1$ ; pd  $z_2$ ; draw  $flex(z_1, z_3, z_2);$  % lobe
draw  $z_1$  --  $z_2$ ; % stem
endchar;

beginpunkchar("E", 12, .5, 1);
 $z_1 = pp(2u, 0); z_2 = pp(2u, h); z_3 = pp(w - 2.5u, h); z_4 = pp(w - 2u, 0);$ 
pd  $z_3$ ; pd  $z_4$ ; draw  $z_4$  --  $z_1$  --  $z_2$  --  $z_3$ ; % stem and arms
 $z_5 = pp(2u, .6h); z_6 = pp(w - 3u, .6h);$ 
pd  $z_5$ ; pd  $z_6$ ; draw  $z_5$  --  $z_6$ ; % crossbar
endchar;

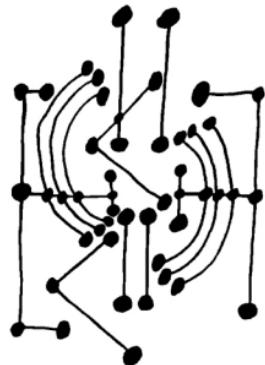
beginpunkchar("F", 12, .5, 2);
 $z_1 = pp(2u, 0); z_2 = pp(2u, h); z_3 = pp(w - 2u, h);$ 
pd  $z_1$ ; pd  $z_3$ ; draw  $z_1$  --  $z_2$  --  $z_3$ ; % stem and arm
 $z_5 = pp(2u, .6h); z_6 = pp(w - 3u, .6h); z_4 = pp.5[z_5, z_6] - (0, .1h);$ 
pd  $z_5$ ; pd  $z_6$ ; draw  $flex(z_5, z_4, z_6);$  % crossbar
endchar;

beginpunkchar("G", 13, .5, .5);
 $z_1 = pp(w - 2u, .8h); z_2 = pp(.6w, h); z_3 = pp(u, .5h);$ 
 $z_4 = pp(.6w, 0); z_5 = (w - 2u, 0);$ 
pd  $z_1$ ; draw  $z_1$  ..  $z_2$  ..  $z_3$  ..  $z_4$  ---  $z_5$ ; % arc
 $z_6 = pp(.5[u, x_5], .4h);$ 
pd  $z_6$ ; pd  $z_5$ ; draw  $z_6$  --  $(pp(x_5, y_6))$  --  $z_5$ ; % spur
endchar;

```

quickly sketched a set of numerals, and raced back to my office. Soon I had a font of 43 characters—26 letters, 10 numerals, and 7 punctuation marks. Whew! I was ready to hand out a sample sheet to everybody at 7 pm, hot off the copy machine.

A year or so later, I was wandering around in Boston's Museum of Fine Arts and I came across a drawing made by Picasso in 1924 [5]; see the illustration at the right. This made me wonder if the **PUNK** fonts weren't really *sixty* years behind the times, not just ten. But I did find a striking confirmation of the relevance of at least part of the **PUNK** design in October 1986, when I chanced to see the following typography on a billboard in the Paris Métro(!):



E

KNUTH

# Computer Modern Typefaces



ADDISON  
WESLEY

13446



COMPUTERS & TYPESETTING

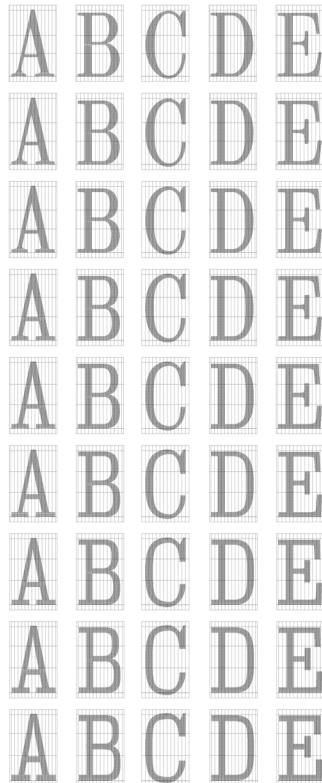
DONALD E. KNUTH

COMPUTERS & TYPESETTING / E

# Computer Modern Typefaces

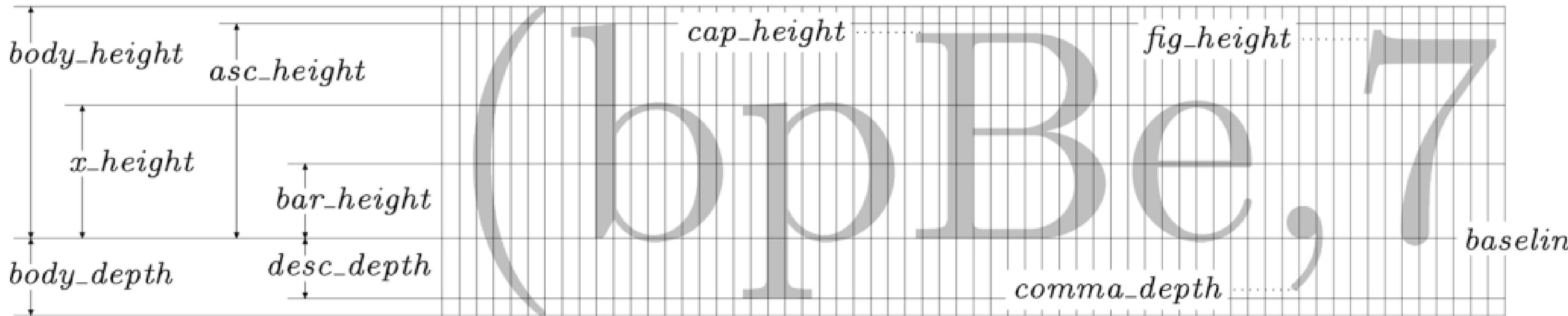
DONALD E. KNUTH

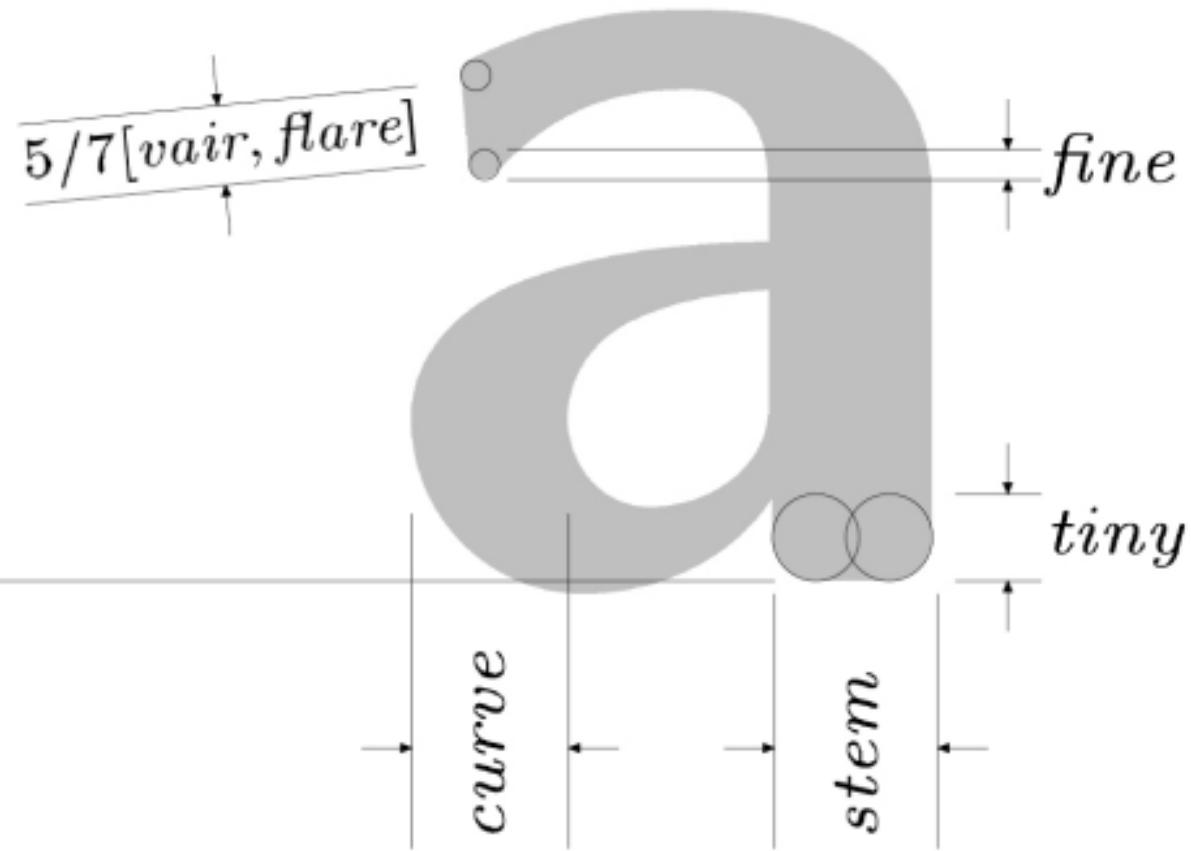
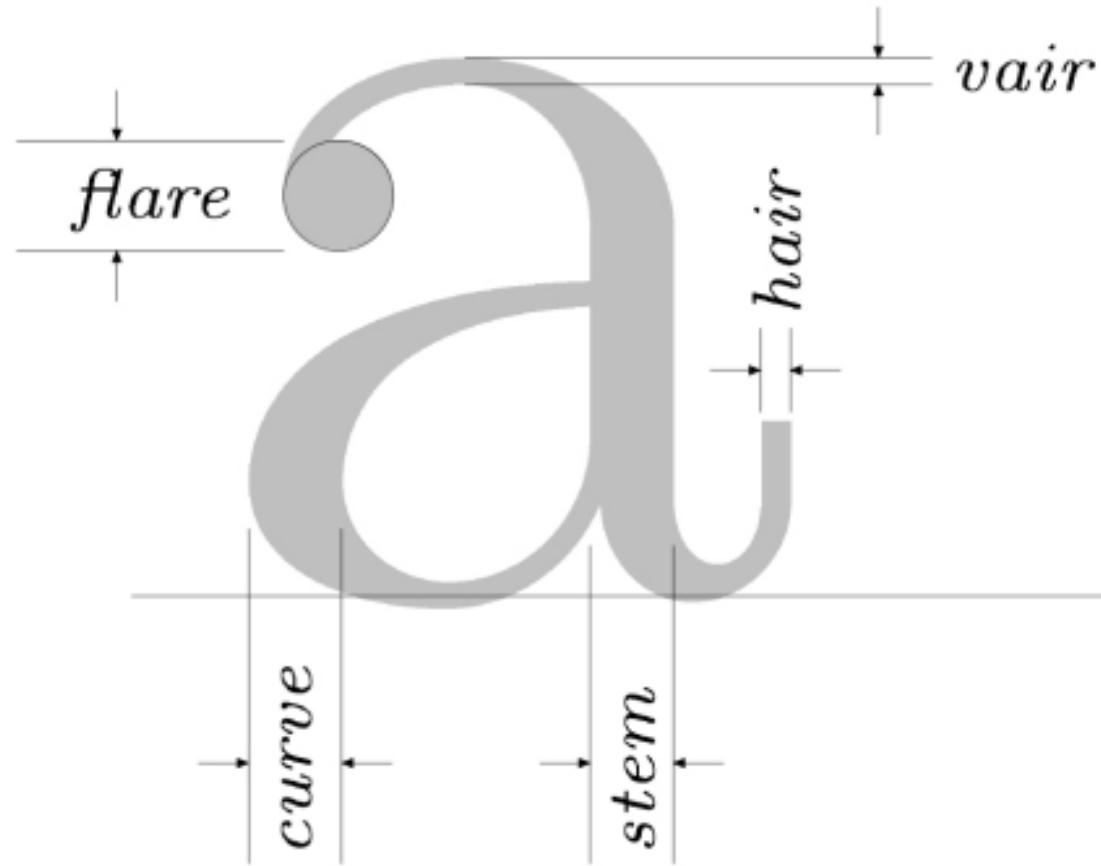
*Stanford University*

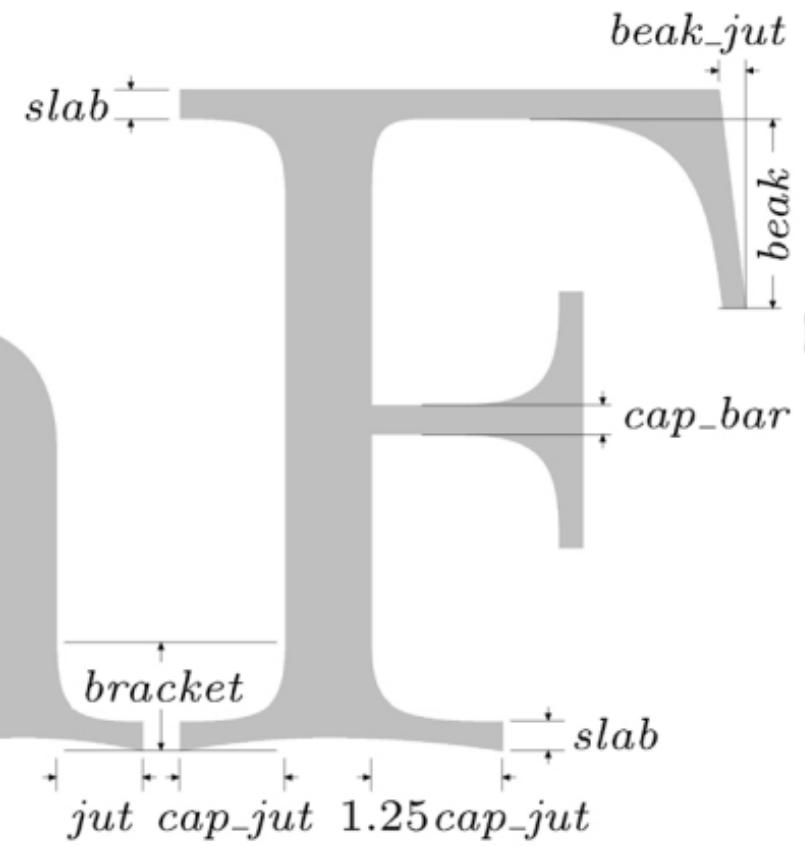
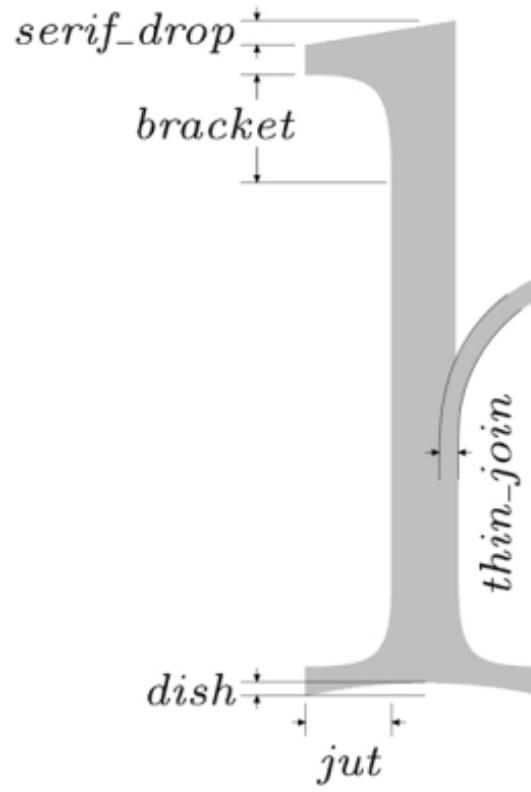


**ADDISON-WESLEY**

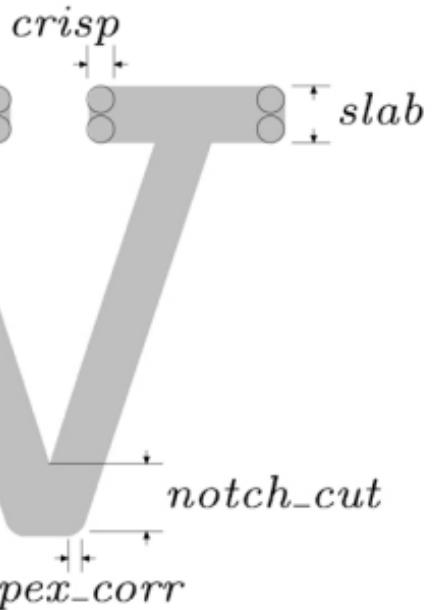
Upper Saddle River, NJ  
Boston · Indianapolis  
San Francisco · New York  
Toronto · Montréal  
London · Munich  
Paris · Madrid  
Capetown · Sydney · Tokyo  
Singapore · Mexico City



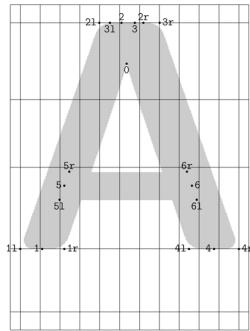
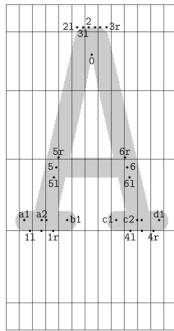
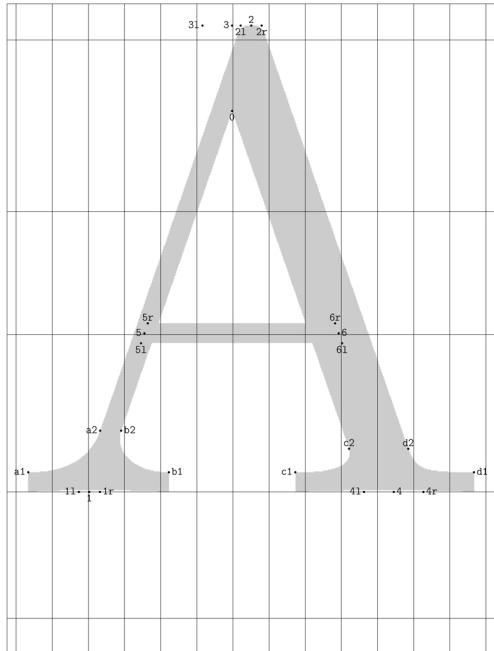




*beak-jut*



368 romanu: ROMAN UPPERCASE



Now we come to program file `romantu.mf`, whose letters are used in all fonts except those containing nothing but math symbols. In fact, `romantu` is used twice in the caps-and-small-caps fonts.

```
% Computer Modern Roman upper case:
% These letters were originally coded by D. E. Knuth in November, 1979,
% inspired by the Monotype faces used in The Art of Computer Programming.
% Sans serif designs by Richard Southall were added in April, 1982.
% The programs were revised for the new METAFONT conventions in 1985.

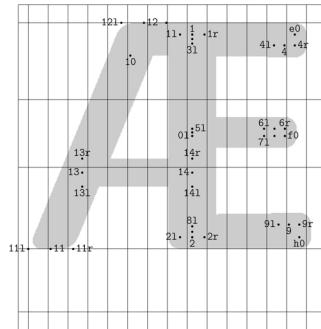
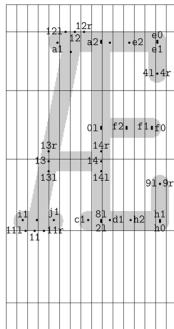
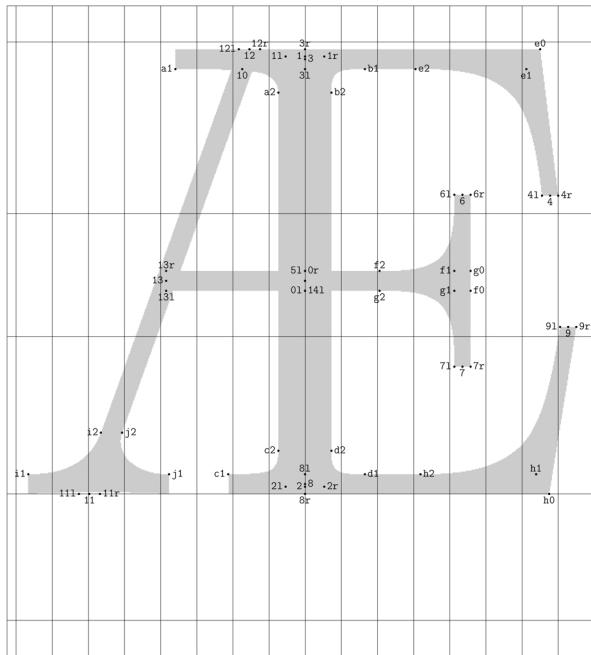
% Character codes '101 through '132 are generated.

cmchar "The letter A";
beginchar("A", 13u#, cap_height#, 0);
adjust_fit(cap_serif_fit#, cap_serif_fit#);
numeric left_stem, right_stem, outer_jut, alpha;
right_stem = cap_stem - stem_corr;
left_stem = min(cap_hair if hefty: -3stem_corr fi, right_stem);
outer_jut = .8cap_jut; x11 = w - x4r = l + letter_fit + outer_jut + .5u; y1 = y4 = 0;
x2 - x1 = x4 - x3; x3r = x2r + apex_corr; y2 = ys = h + apex_o + apex_oo;
alpha = diag_ratio(2, left_stem, y2 - y1, x4r - x1l - apex_corr);
penpos1(alpha * left_stem, 0); penpos2(alpha * left_stem, 0);
penpos3(alpha * right_stem, 0); penpos4(alpha * right_stem, 0);
z0 = whatever[z1r, z2r] = whatever[z3l, z4l];
if y0 < h - cap_notch_cut: yo := h - cap_notch_cut;
fill z0 + .5right{down} ... {z4 - z3}diag_end(3l, 4l, 1, 1, 4r, 3r)
-- diag_end(4r, 3r, 1, 1, 2l, 1l) -- diag_end(2l, 1l, 1, 1, 1r, 2r){z2 - z1}
... {up}z0 + .5left -- cycle;                                         % left and right diagonals
else: fill z0 -- diag_end(0, 4l, 1, 1, 4r, 3r) -- diag_end(4r, 3r, 1, 1, 2l, 1l)
-- diag_end(2l, 1l, 1, 1, 1r, 0) -- cycle; fi                         % left and right diagonals
penpos5(whatever, angle(z2 - z1)); z5 = whatever[z1, z2];
penpos6(whatever, angle(z3 - z4)); z6 = whatever[z3, z4]; y6 = y5;
if hefty: ys fi = 5/12yo;                                              % bar line
ysr - y5l = y6r - y6l = cap_band; penstroke z5e -- z6e;
if serif: numeric inner_jut; pickup tiny.nib;
prime_points_inside(1, 2); prime_points_inside(4, 3);
if rt x1r + cap_jut + .5u + 1 ≤ lft x4l - cap_jut: inner_jut = cap_jut;
else: rt x1r + inner_jut + .5u + 1 = lft x4l - inner_jut; fi
dish_serif(1', 2, a, 1/2, outer_jut, b, .6, inner_jut)(dark);           % left serif
dish_serif(4', 3, c, 1/2, inner_jut, d, 1/3, outer_jut); fi             % right serif
penlabels(0, 1, 2, 3, 4, 5, 6); endchar;
```

*On the breast of her gown, in fine red cloth,  
surrounded with an elaborate embroidery  
and fantastic flourishes of gold-thread,  
appeared the letter A.*

— NATHANIEL HAWTHORNE, *The Scarlet Letter* (1850)

452 romspu: SPECIAL UPPERCASE FOR ROMAN



```

cmchar "The ligature AE";
beginchar(oct "035", 16u#, cap_height#, 0);
italcorr cap_height#* slant - beak_jut# -.5u#;
adjust_fit(cap_serif_fit#, 0);
numeric left_stem, mid_stem, outer_jut, alpha;
mid_stem = max(tiny_breadth, hround(.9[mfudged.hair, mfudged.cap_stem]));
pickup tiny.nib; pos_1(mid_stem, 0); pos_2(mid_stem, 0);
lft x_1l = lft x_2l = hround(if monospace or hefty: .55 else: .5 fl w -.75u);
top y_1 = h; bot y_2 = 0;
filldraw stroke z_1e -- z_2e; % stem
pickup crisp.nib; pos_3(slab, 90); pos_4(mfudged.hair, 0);
top y_3r = h; x_3 = x_1; rt x_4r = hround(w - u); y_4 = good.y(y_3l - beak) - eps;
arm(3, 4, e, beak_darkness, beak_jut); % upper arm and beak
pos_5(cap_bar, -90); pos_6(mfudged.hair, 0); x_5 = x_1;
top y_5l = hround(if hefty: .52 else: .48 fl [y_2, y_1] + .5cap_bar);
pos_0(cap_bar, 90); pos_7(mfudged.hair, 0);
z_0 = z_5; x_6 = x_7; y_6 - y_5l = y_0 - y_7;
if serifs and not(monospace and hefty): rt x_6r = hround(w - 3.65u + .5mfudged.hair);
y_6 = good.y(y_5l + .6beak) + eps; rt x_9r = hround(w -.5u);
else: rt x_6r = hround(w - 1.5u); y_6 = y_5l + eps; rt x_9r = hround(w -.75u); fl
arm(5, 6, f, beak_darkness, 0); arm(0, 7, g, beak_darkness, 0); % middle arm and serif
pos_8(slab if not serif: + 2stem_corr fl, -90);
pos_9(mfudged.hair, 0); bot y_8 = 0; x_8 = x_2; y_9 = good.y(y_8l + 7/6beak) + eps;
arm(8, 9, h, beak_darkness, 1.5beak_jut); % lower arm and beak
left_stem = if monospace: fudged.hair else: cap_hair fl if hefty: -3stem_corr fl;
outer_jut = .8cap_jut; x_11l = l + letter_fit + outer_jut + .5u; y_11l = 0;
x_12 = x_11 - apex_corr - if monospace: 2 fl u; y_12 = h;
alpha = diag_ratio(1, .5left_stem, y_12 - y_11, x_12 - x_11l);
penpos_11(alpha * left_stem, 0); penpos_12(alpha * left_stem, 0);
fill diag_end(12l, 11l, 1, 1, 11r, 12r)
-- diag_end(11r, 12r, 1, 1, 12l, 11l) -- cycle; % diagonal
y_10 = h - slab; z_10 = whatever[z_11, z_12];
fill z_10 -- (x_1, y_10) -- (x_1, h) -- z_12 -- cycle; % link
penpos_13(whatever, angle(z_2 - z_1)); z_13 = whatever[z_11, z_12];
penpos_14(cap_band, 90); x_14 = x_0; y_13l = y_14l; y_13r = y_14r;
if hefty: y_14r = .4h; else: y_14 = y_0; fl
penstroke z_13e -- z_14e; % bar line
if serifs: numeric inner_jut; pickup tiny.nib;
prime_points_inside(11, 12);
if rt x_11r + cap_jut + .5u + 1 <= lft x_2l - .75cap_jut: inner_jut = cap_jut;
else: rt x_11r + inner_jut + .5u + 1 = lft x_2l - .75inner_jut; fl
dish_serif(11', 12, i, 1/2, outer_jut, j, .6, inner_jut)(dark); % lower left serif
nodish_serif(1, 2, a, 1/3, cap_jut + x_1l - x_12, b, 1/3, .5cap_jut); % upper serif
nodish_serif(2, 1, c, 1/3, .75inner_jut, d, 1/3, .5cap_jut); fl % lower middle serif
penlabels(0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14); endchar;

```



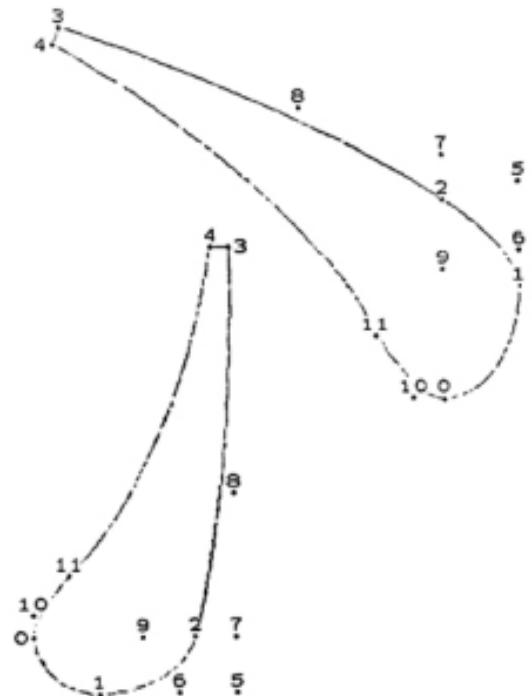


FIGURE 8.



FIGURE 9.



Een ding is zeker,  
tijdens de overgang  
naar het nieuwe  
millennium zullen  
bij ons de kaarsen  
blijven branden.

Wij wensen u een  
goede 21<sup>e</sup> eeuw toe.

PRAGMA ADE  
Ridderstraat 27  
8001 GH Hasselt NL

+31 38 477 53 69  
[www.pragma-ade.nl](http://www.pragma-ade.nl)



FIGURE 13. Red letters on a green grid (at 50% of the original size).

### 1981: Madonna and Child

Our typographic card of 1981 featured St. Luke's Christmas story:

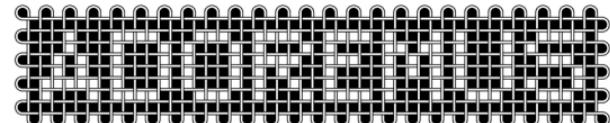
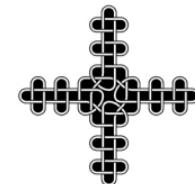
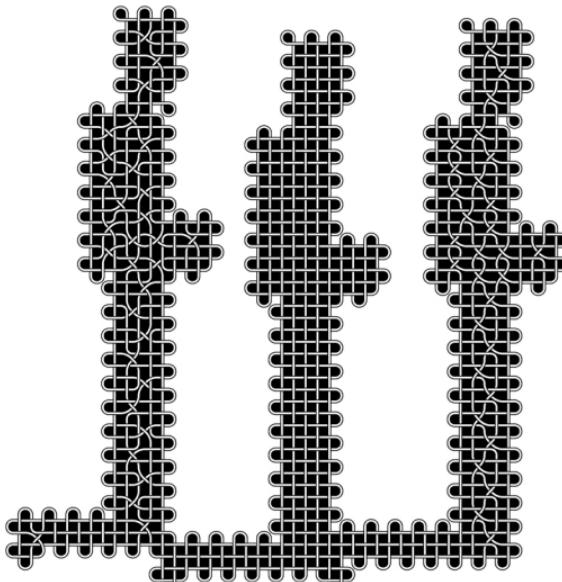
\* \* \* \*

\* At that time \*  
 \* the emperor, Cæsar \*  
 \* Augustus, ordered a cen- \*  
 \* sus to be taken throughout \*  
 \* the Roman Empire. This first \*  
 \* census was conducted when Qui- \*  
 \* rinius was the governor of Syria. \*  
 \* Everyone, then, went to register \*  
 \* himself, each to his own home \*  
 \* town. \* Joseph went from the \*  
 \* town of Nazareth in Galilee \*  
 \* south to the town of Bethlehem \*  
 \* in Judea, the birthplace of King \*  
 \* David, because he was a descend- \*  
 \* ant of David. He went to register \*  
 \* with Mary, who was promised in \*  
 \* marriage to him. Mary was pregnant, \*  
 \* and while they were in Bethlehem, the \*  
 \* time came for her to have her baby. She gave \*  
 \* birth to her first son, wrapped him in cloths and laid \*  
 \* him in a manger—there was no room for them to stay at \*  
 \* the inn. \* Some shepherds were in that part of the country \*  
 \* spending the night in the fields, taking care of their flocks. An \*  
 \* angel of the Lord appeared to them, and the glory of the Lord shone \*  
 \* over them. They were terribly frightened, but the angel said to them, \*  
 \* "Don't be afraid! I am here with good news for you, which will bring great joy \*  
 \* to all the people. This very day in David's town your Savior was born—Christ \*  
 \* the Lord! And this is what will prove it to you: you will find a baby wrapped in \*  
 \* cloths and lying in a manger." \* Suddenly a great army of heaven's angels appeared \*  
 \* with the first angel, singing praises to God: "Glory to God in the highest heaven, and \*  
 \* peace on earth to those with whom he is pleased!" \* When the angels went away from \*  
 \* them back into heaven, the shepherds said to each other, "Let's go to Bethlehem and see \*  
 \* what has happened, as the Lord has told us." \* They hurried off and found Mary and Joseph \*  
 \* and saw the baby lying in the manger. The shepherds told them what the angel had said \*  
 \* about the child. All who heard it were amazed at what the shepherds said. Mary remembered \*  
 \* all these things and thought deeply about them. \* Then the shepherds went back, singing \*  
 \* praises to God for all they had heard and seen; it had been just as the angel had told them.

**1985: Adoremus**

And a few years later I used typography in yet another way.

Our Christmas card, "Let us adore," contains a little puzzle for those of you who like a challenge. Can you determine how many separate strands of cord have been looped together to make the knots in the design? For example, the star breaks down into eight short loops and two longer loops. How many strands are in "Adoremus"? How many appear in the three kings?



## 1989: Additional Specialty Fonts

Our Christmas card for 1989 (Figure 14), and its accompanying newsletter, introduced an experimental typeface called 'JEN', based on my daughter's handwriting. (1989 was the year that I added fancy new ligature mechanisms to the *TEX* and *METAFONT* systems, thereby enabling fonts such as this.) We also spruced things up by using another new font, 'HOLLY', for decorative effects of various kinds.

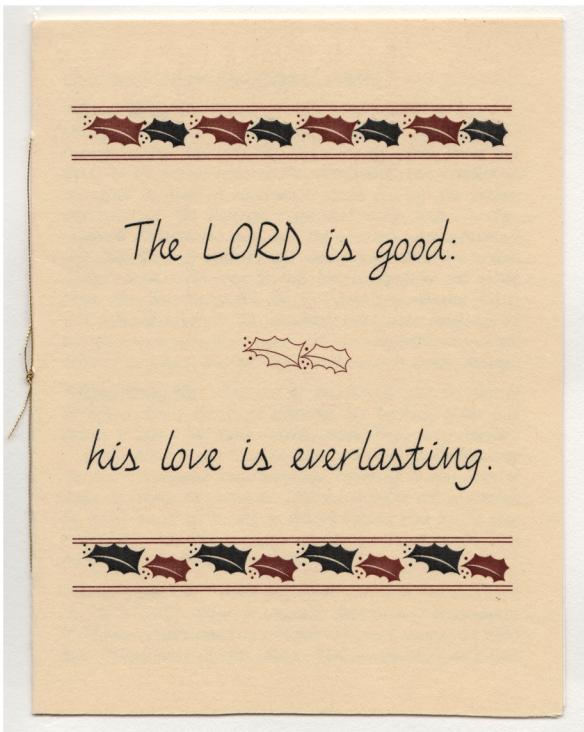
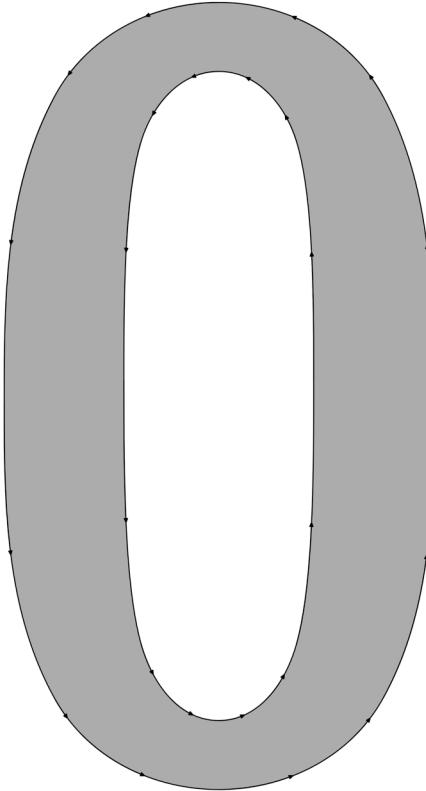


FIGURE 14.  
HOLLY + JEN  
+ Psalm 136:1  
(reduced to 55%).



**Figure 2.** The glyph of the numeral 0 in xmssdc10.mf font.

Fig. 2 shows a glyph only made by two contours which are the result of penpos and penstroke macros. Of course we could obtain the same result drawing 24 curve sections (12 for the outer contour, 12 for the inner one) but it should be clear that the METAFONT description is much more straight or, at least, “typographic”.

Things completely change when we consider the numeral 2:

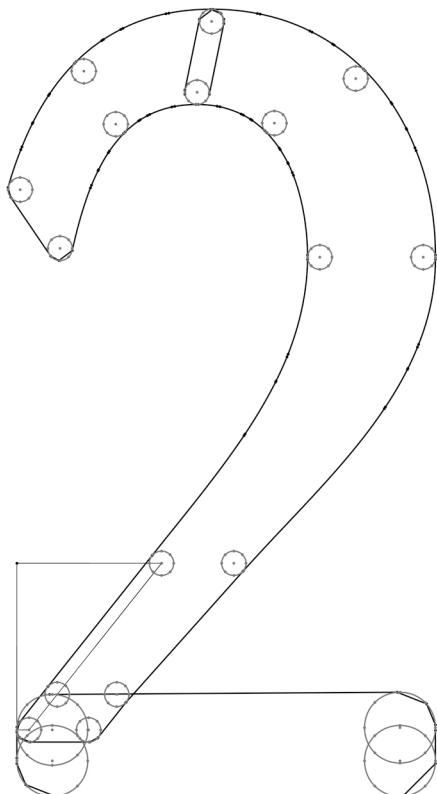
```
cmchar "The numeral 2";
beginchar("2",9u#,fig_height#,0);
italcorr fig.height##*slant-.5u#;
adjust_fit(0,0);
numeric arm_thickness, hair_vair;
hair_vair=.25[vair,hair];
arm_thickness=
```

```
Vround(if hefty:slab+2stem_corr
      else: 4[stem,cap_stem] fi);
pickup crisp.nib;
pos7((arm_thickness,-90); pos8(hair,0);
bot y7r=0; lft x7=rround .9u; rt x8r=rround(u-.9u);
y8=good.y(y7l+beak/2)+eps;
arm(7,8,a,.3beak_darkness,beak_jut);%arm and beak
pickup fine.nib; pos2(slab,90);
pos3(.4[curve,cap_curve],0);
top y2r=h+o; x2r=.5(u-.5u);
rt x3r=rround(u-.9u); y3r+.5vair=.75h;
if serifs:
  numeric bulb_diam;
  bulb_diam=rround(flare+2/3(cap_stem-stem));
  pos0(bulb_diam,180); pos1(cap_hair,180);
  lft x1r=rround .9u; y1r=.5bulb_diam=2/3h;
  (x,y1l)=whatever[z1l,z2r];
  x2l=-x; bulb(2,1,0); % bulb and arc
else: x2l=-x2l-.25u; pos1flare,angle(-9u,h));
  lft x1r=rround .75u; bot y1l=vround .7h;
  y1r=good.y y1r+eps; x1l=good.x x1l;
  filldraw stroke term.e(2,1,lefth,.9,4);
fi % terminal and arc
pos4(.25[hair_vair,cap_stem],0);
pos5(hair_vair,0);
pos6(hair_vair,0);
y5=arm_thickness; y4=.3[y5,y3];
top y6=min(y5,slab,top y7l);
lft x6l=crisp.lft x7;
z4l=whatever[z6l,(x3l,bot .58h)];
z5l=whatever[z6l,z4l];
erase fill z4l--;
z6l--lft z6l--;
(lft x6l,y4l)--cycle;%erase excess at left
filldraw stroke z2e(right)..tension
  atleast .9 and atleast 1
  ..z3e(down)..(z5e-z4e)z4e-z5e--z6e;%stroke
penlabels(0,1,2,3,4,5,6,7,8);
endchar;
```

As we can see in fig. 3, there are both a contour and envelopes of more than a pen; there are intersections between the contour the envelopes and the pens, and some curves are outside the glyph (some of these curves are used to delete unwanted black pixels). There are also some unexpected straight lines and small curves. The number of curves looks quite large, which is not what we desire as we want to obtain the outline depicted in fig. 4.

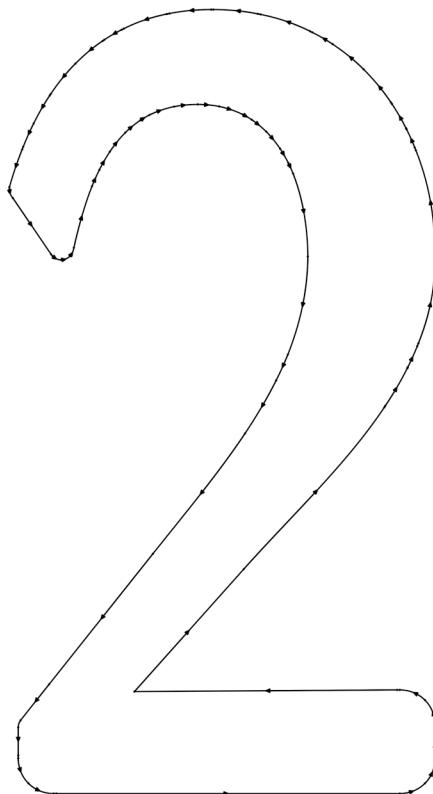
Unfortunately, things are even different and it's necessary to describe how METAFONT calculates pen envelopes to go on. This is explained in the book “METAFONT: The Program” (KNUTH, 1986a) at the ““Polygonal pens” part, chapter 469, that we briefly quote with a slightly modified notation:

Given a convex polygon with vertices  $\mathbf{w}_0, \mathbf{w}_1, \dots, \mathbf{w}_{n-1}, \mathbf{w}_n = \mathbf{w}_0$  a in a *counter-clockwise* order ... (and a curve  $\mathbf{B}(t)$ ) the envelope is obtained if we offset  $\mathbf{B}(t)$  by  $\mathbf{w}_k$  when the curve is travelling in a direction  $\mathbf{B}'(t)$  lying between the directions  $\mathbf{w}_k - \mathbf{w}_{k-1}$  and



**Figure 3.** The glyph of the numeral 2 in xmssdc10 font. We can see envelopes and pens (thick curves) and a contour (thin curve).

$w_{k+1} - w_k$ . At times  $t$  when the curve direction  $B'(t)$  increases past  $w_{k+1} - w_k$ , we temporarily stop plotting the offset curve and we insert a straight line from  $B(t) + w_k$  to  $B(t) + w_{k+1}$ ; notice that this straight line is tangent to the offset curve. Similarly, when the curve direction decreases past  $w_k - w_{k-1}$ , we stop plotting and insert a straight line from  $B(t) + w_k$  to  $B(t) + w_{k-1}$ ; the latter line is actually “retrograde” step which will not be part of the final envelope under the METAFONT’s assumptions. The result of this construction is a continuous path



**Figure 4.** An outline of the numeral 2 in xmssdc10.mf font.

that consist of alternating curves and straight line segments.

This explains why the number of the curves is large and why there are small curves, but says nothing about those circular curves that we can see in fig. 4: METAFONT indeed converts an elliptical pen into a polygonal one and then applies the algorithm. The conversion is accurate enough to guarantee that the envelope is correctly filled with the right pixels. This is a key point to understand: *METAFONT’s main task is to produce the best bitmap of a glyph, not the best outline*.

The role of the sensors is to gather as much information as possible about pixels, contours, the polygonal version of the pens, envelopes and their straight lines

METAFONT

ELHTON



METAFONT