Three Fonts of Computer-drawn Letters

M. V. Mathews, Carol Lochbaum, and Judith A. Moss

Detailed descriptions are given for three fonts of letters. Letter shapes are entirely described by numbers. The basic vectors are in a general form so the fonts may be easily drawn on a variety of computers and cathode ray tubes. The fonts include both upper- and lower-case Roman letters, mathematical signs, and upper- and lower-case Greek letters. Digital type design is described. However, the principal contribution is the fonts themselves.

A digital computer can control a cathode ray tube so as to draw almost any black and white picture, including type fonts. Drawing type fonts has proven to be an exceedingly useful output for editing and text manipulating programs.[1] In this paper three fonts of letters are described which are useful as a computer output medium for many applications. The fonts include both lower- and upper-case Roman letters in three sizes, lower- and upper-case Greek letters in two sizes, digits in three sizes, and an assortment of mathematical symbols in three sizes.

The letters are formed by a number of vectors (short straight lines) drawn on a computer-controlled cathode ray tube. The characters are photographed from the tube. An average of twenty-five vectors-per-character is used; hence quite detailed control of character shape is achieved.

The shape is specified by a numerical vector table stored in the computer memory; thus great flexibility in changing or adding characters is inherent. The numerical table of vectors may be obtained in machine-readable form for use in other computers.

The fonts were originally designed to be produced on a Strom-

1. M. V. Mathews and Joan E. Miller, "Computer Editing, Typesetting and Image Generation," *American Federation of Information Processing Societies Conference Proceedings,* 1965 Fall Joint Computer Conference, Vol. 27, Part 1 (Washington, D.C.: Spartan Books), pp. 389-398.

berg-Carlson 4020 microfilm printer. This device has a 1024 raster of computer-addressable points. A vector can be drawn between any two points. The resolution is limited by the width of the vector, which is about 2.3 raster points. The normal output is on 35 mm. microfilm which can be enlarged onto hard copy. The final sizes of the fonts depend on the degree of enlargement. Normally the middle-sized font would be used for standard text, the small size for footnotes and subscripts, and the large size for titles. There is, of course, no limitation to these uses. The relative sizes of the three fonts are in the ratio of 1 to 1½ to 2.

The quality of the Stromberg-Carlson 4020 is just acceptable for 8½ by 11-inch pages. The fonts should be useful on any other cathode ray device having this good or better a raster and resolution. In particular, current announced devices which have 4096 x 4096 rasters and correspondingly improved resolutions should produce excellent 8½ by 11-inch quality.

The main contribution of this paper is the fonts. However, their creation led to a new skill—digital type design. Some of the art of this design is discussed. In particular, it is possible to greatly increase the quality of the images by properly placing the vectors and characters with respect to the raster of the cathode ray tube. The advantage thus gained has not been quantitatively measured, but we estimate it to be equivalent to doubling the resolution.

Digital Type Design

Digital type design consists in determining the coordinates of the vectors which form the image of a letter. Selection of vectors to best fit a raster requires judgment and practice. The process is best illustrated by a few example characters from our digital approximation to a font in the Baskerville style of type. This style was selected after trying several others (including a sans-serif variety) because it produced the most readable characters with the limited resolution available.

Figure 1 shows a completed design for the Q and i of Font Three, the largest of the fonts. An enlargement of a letter is placed on a suitably-scaled raster, and the appropriate vectors chosen visually. The outline vectors closely match the contours of the letter

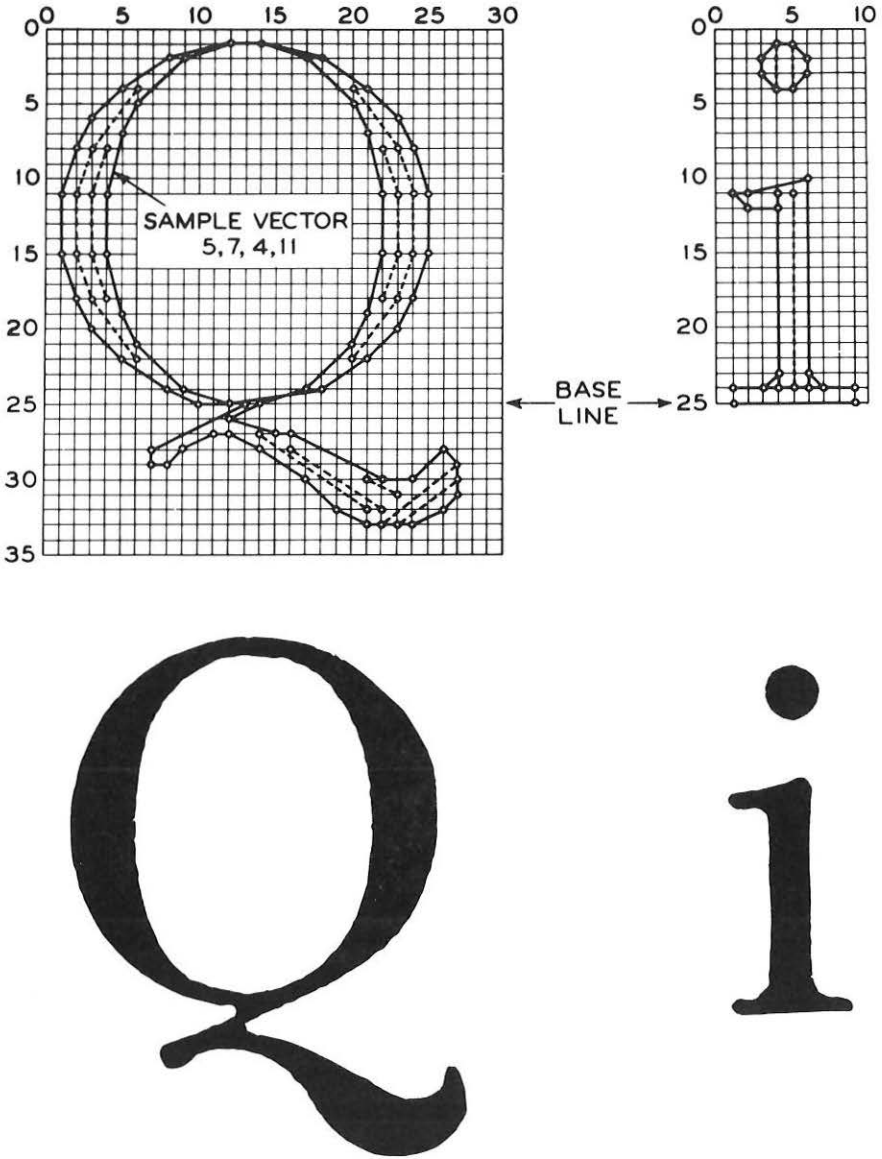

Figure 1. Upper case Q and lower i of Font Three. Above are the actual vectors used to design the characters. Open dots are the coordinates of the vectors. Dotted lines are "fillers" which shade in the characters. Below are the photographic enlargements of the Baskerville characters.

Figure 2. Font One

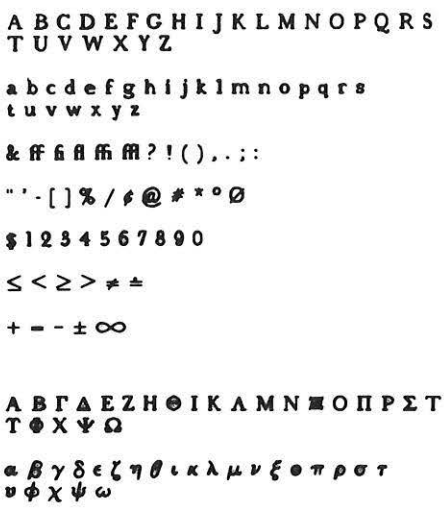

Figure 3. Font Two

Figure 4. Font Three

A B C D E F G H I J K L M N O P
Q R S T U V W X Y Z

a b c d e f g h i j k l m n o p q r s
t u v w x y z

ff fi fl ffi ffl

1 2 3 4 5 6 7 8 9 0

TABLE I. *Format of computer cards specifying characters*

Column

2	3	6	8	16	24	32	40	48	56	64	72
3		72	29	12 114	114 118	218 221	421 423	623 624	824 825	11251125	15251524
3		72	29	24182320	23202122	21221824	18241225	12251025	1025 824	824 522	522 320
3		72	29	320 218	218 115	115 111	111 2 8	2 8 3 6	3 6 5 4	5 4 8 2	8 212 1
3		72	29	12 1 9 2	9 2 6 5	6 5 5 7	5 7 411	411 415	415 519	519 621	621 924
3		72	29	9241225	6 4 3 8	3 8 211	211 215	215 318	318 622	418 315	315 311
3		72	29	311 4 8	14 117	217 220	520 521	721 72211	22112215	22152119	21192021
3		72	29	20211724	17241425	20 423	823 82411	24112415	24152318	23182022	22 82311
3		72	29	23112315	23152218	1325 728	728 729	729 829	829 928	92811271	11271227
3		72	29	12271428	14281730	17301932	19322133	21332433	24332632	26322731	27312729
3		72	29	27292628	26282430	24302230	22301627	16271527	15271226	12261425	14272132
3		72	29	16282232	21302331	22332729	23332730				

The eleven computer cards above give all the information necessary to draw the Q illustrated in Figure 1. The quantities in all fields are right adjusted. Each card has the following format:

Field	*Column(s)*	*Description*
1	1-2	The font number: 1, 2, or 3.
2	3	Blank or E (See description of field 3 below.)
3	4-6	Numerical character code number. See Table II for the correspondence between the contents of columns 3-6 and the identification of the character.
4	7-8	Width of the character.
5-36	9-72	The remainder of the card is divided into thirty-two fields of two columns each. Each of eight successive groups of four fields describes one vector. In the example above, the first vector is drawn between coordinate points (12,1) and (14,1); the second between (14,1) and (18,2); etc.

outline except that both ends of each vector must lie on a raster point. The outline vectors are shown as solid lines with small circles indicating beginnings and ends. Other vectors shown as dashed lines fill the interior of the letter. These also must end on raster points.

Each character was designed on a grid with the origin of the vector coordinates (point [0, 0]) at the upper left-hand corner of the grid. All vectors for a given character are relative to this origin. Thus, the sample vector in Figure 1 is described by the four numbers 5, 7, 4, 11 giving, respectively, the horizontal and vertical components of one end point of the vector and then the other. In the course of typesetting, any character can be translated to any origin on microfilm by means of simple additions. The base line for Font Three is at vertical coordinate 25. The base line is the imaginary line upon which most alphabetic characters sit, except those such as p, which have descenders. These characters sit on the descender line, which is at vertical coordinate 33 for Font Three. All measurements are in units of raster spaces. The width of the character is defined such that it is actually larger than the minimum number of raster spaces occupied by the character. The additional empty space assures that the next character in a horizontal line of type will be correctly placed relative to the current character when the width of the current character is added to its origin on the microfilm.

The card decks for the complete fonts are too long to list here. Requests for this material may be directed to the authors.

The vectors as drawn by the cathode ray tube have a substantial width which must be considered in designing the letters. Figure 5 gives some idea of width on the Stromberg-Carlson 4020. The single vector shown in Figure 5A will be drawn as a line about two raster spaces thick surrounding the vector as indicated in Figure 5B. A double vector will produce two shades of grey as shown in Figures 5C and 5D. Although these line widths are specific to the Stromberg-Carlson 4020, other equivalent widths would apply to other cathode ray tubes.

A useful method of producing intermediate line widths is illustrated in Figure 6. In some cases the double vectors in Figure 6A produce too-thick letters and the single vectors in Figure 6B pro-

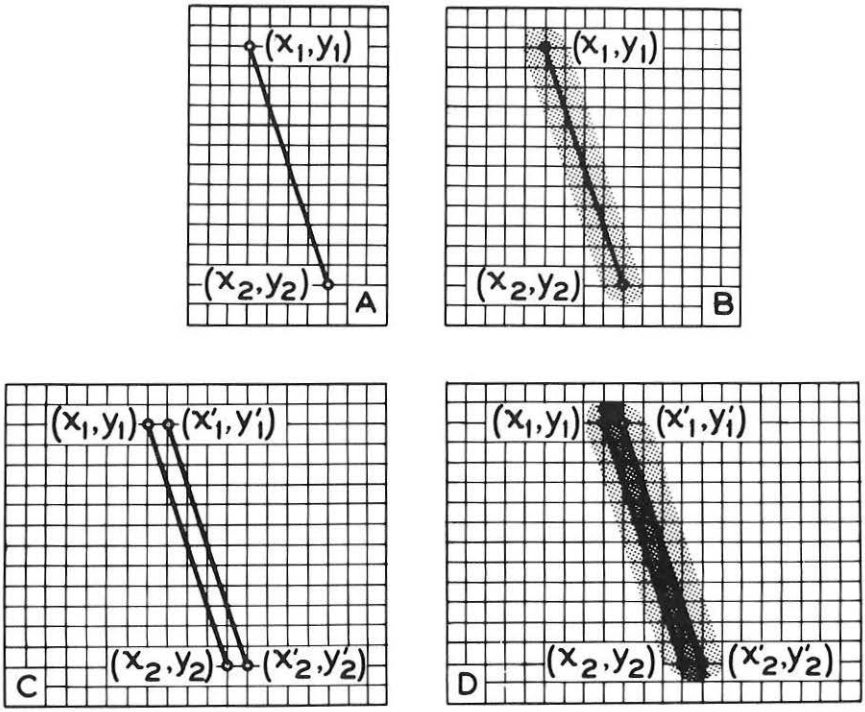

Figure 5. In 5A the single vector drawn between (x_1, y_1) and (x_2, y_2) is presented on the cathode ray tube as in 5B, a line the thickness of two raster spaces with rounded ends. The double vector of 5C is presented as a line the thickness of three raster spaces with some overlap in the center, as in 5D.

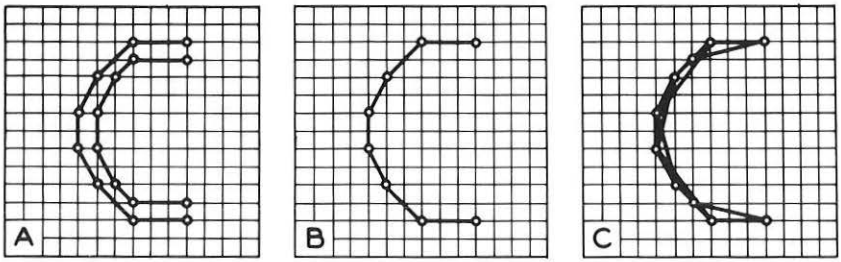

Figure 6. The double row of vectors of 6A produces a shape which is too thick, while the single row of 6B gives a shape which is too thin. The disarrangement of vectors in 6C gives an intermediate thickness.

duce too-thin letters. The interlaced vectors in Figure 6C may yield a more desirable thickness.

Cathode Ray Tube

A brief description of the Stromberg-Carlson 4020 will assist in using the vector letters with other machines.

The SC 4020 has two modes of operation. First, it can draw vectors, which can start at any raster point on its 1024 x 1024 grid and extend up to sixty-four grid spaces in either or both x and y directions. Secondly, it can produce a total of sixty-four different characters by shaping the electron beam with an appropriate mask in the cathode ray tube. One character is a dot. This mode allows one to construct shapes using closely spaced dots, or any other available character, as building blocks. In the type fonts described here, only the vector mode of operation was used. Measurement of the width of the vector indicates that it is equal to 2.3 grid spaces. This means that a character which is twenty-three grid spaces high has a resolution of only ten vector widths.

Conclusions

Digital fonts have many advantages over other methods of forming characters. Drawing on a cathode ray tube is inherently a fast process, and speeds from 1,000 to 10,000 characters per second are practical with equipment which is especially designed for this purpose. The fonts are inherently extendable. A new font consists merely of a collection of numbers put in the computer memory. Even more important is the ease with which special characters may be added to an existing font. The digital description of these characters may be inserted at any point in the stream of input text to the character-drawing computer. Furthermore, since the image is described in complete generality digitally, such things as line drawings, mathematical equations, and musical scores can be drawn by the same, completely standard, means.

Digital type design raises a unique problem of combining computer technology with the type designer's art and artistry. The existing designs have been prepared by mathematicians and engineers aided by a small amount of consultation with a type de-

signer. Eventually, to achieve high-quality fonts, type designers will have to assume this job and will have to learn enough computer technology to express their designs in this new digital language. Merely copying existing fonts has severe limitations. As type designers come to understand the digital technology, they will be able to design fonts which are not only pleasing to see but well adapted to the computer in terms of being fast to draw and compact in their digital description.

It is clear from the number of vectors in letters that manual design of a font is a tedious process. Both semi-automatic design and completely automatic design are possible. For semi-automatic design the designer would use a graphic computer[2] and draw the vectors on the face of a cathode ray tube with a light pen. Once the vectors were drawn, their digital description would be known by the graphic computer. A completely automatic method is conceivable if one is willing to simplify the vectors by requiring that they all be parallel (vertical or horizontal). In this case, a simple scanner could be designed to determine the digital coordinates of the vectors by automatically scanning an enlarged image of the letter.

The three fonts of letters presented here are the beginning of a great variety of possible fonts and characters which will be numerically described and computer drawn. The generality of the representation is clear from the ease with which the vectors can be adapted to other computers and other cathode ray tubes. We believe the fonts will have great utility.

2. W. H. Ninke, "GRAPHIC 1—A Remote Graphical Display Console System," *IFIPS Conference Proceedings,* 1965 Fall Joint Computer Conference, Vol. 27, Part 1 (Washington, D.C.: Spartan Books), p. 839.

TABLE II. *Specifications of the fonts*

	Font 1	*Font 2*	*Font 3*
Minimum line spacing	18	27	36
Base line	12	18	25
Descender line	16	24	33

Character	Code Number	Font Widths Font 1	Font 2	Font 3	Character	Code Number	Font Widths Font 1	Font 2	Font 3
a	25	9	12	16	A	89	14	22	27
b	32	9	16	18	B	96	12	18	23
c	41	8	13	16	C	105	11	19	25
d	43	9	16	19	D	107	13	22	27
e	42	9	13	16	E	106	11	17	22
f	13	8	11	14	F	77	10	17	20
g	15	10	13	19	G	79	13	20	27
h	34	10	17	20	H	98	12	21	29
i	24	5	9	11	I	88	7	11	14
j	14	6	9	13	J	78	9	15	18
k	40	9	15	20	K	104	12	19	25
l	35	6	10	12	L	99	11	18	24
m	31	15	25	30	M	95	15	26	32
n	44	10	17	21	N	108	14	22	28
o	19	9	14	18	O	83	12	19	27
p	10	9	16	21	P	74	11	20	22
q	8	9	14	22	Q	72	13	20	29
r	27	8	12	16	R	91	13	20	26
s	18	7	9	12	S	82	8	13	17
t	46	7	10	13	T	110	13	20	28
u	45	10	17	22	U	109	13	22	28
v	29	10	14	20	V	93	13	20	26
w	16	13	19	27	W	80	18	27	36
x	47	9	15	21	X	111	13	21	28
y	2	9	15	19	Y	66	11	20	25
z	62	7	12	15	Z	126	10	16	21
					ff	53	13	17	21
					fi	54	9	16	18
					fl	55	10	16	19
					ffi	118	15	22	28
					ffl	119	15	23	28
					1 one	63	8	13	17
					2 two	60	8	13	17
					3 three	61	8	13	17
					4 four	51	8	13	17
					5 five	58	8	13	17
					6 six	56	8	13	17
					7 seven	59	8	13	17
					8 eight	57	8	13	17
					9 nine	48	8	13	17
					0 zero	50	8	13	17

Character	Code Number	Font Widths Font 1	Font 2	Font 3
& ampersand	123	11	17	
' apostrophe	26	4	6	7
* asterisk	121	8	10	
@ at, each	124	16	25	
[bracket, square left	30	5	8	10
¢ cents	120	8	13	
: colon	75	5	6	8
, comma	9	4	7	7
— dash	0	5	8	10
$ dollars	115	8	15	
= equals	12	12	15	
# number	125	12	21	
(parenthesis, left	112	5	7	8
) parenthesis, right	114	5	8	9
% percent	122	13	21	
. period	28	5	8	8
+ plus	76	12	16	
± plus or minus	127	12	16	
? question mark	67	7	12	15
" quotation mark	90	5	8	8
; semicolon	11	4	6	7
/ slash	3	9	14	17
space	4	7	11	15
_ underline	64	10	15	
| absolute value of	E 84		4	

Character	Code Number	Font Widths Font 1	Font 2	Font 3
∢ angle	E 74		17	
≒ approximately equals	E 54	12	15	
] bracket, square right	E 58	5	8	10
c/o care of	E 85		20	
† dagger	E 80		14	
° degree	E 56	7	8	
÷ divided by	E 75		16	
! exclamation point	E 57	6	8	7
≡ identically equals	E 65		15	
↔ iff notation	E 66		15	
→ implication notation	E 67		15	
△ increment	E 73		16	
∞ infinity	E 59	24	32	
∫ integral	E 83		13	
< less than	E 52	13	15	
≤ less than or equals	E 51	13	15	
− minus	E 60	9	14	
> more than	E 55	13	15	
≥ more than or equals	E 53	13	15	
× multiplied by	E 82		13	
≠ not equal to	E 50	12	15	
∥ parallel	E 81		8	
(parenthesis, small left	E 77		5	
) parenthesis, small right	E 76		5	
∂ partial differentiation	E 79		15	
⊥ perpendicular	E 78		16	
" quotation, double left	E 63		12	14
" quotation, double right	E 64		12	14
' quotation, single left	E 61		6	7
' quotation, single right	E 62		6	7
√ root	E 72		11	
ϕ slashed O	E 49	13	21	
⊆ ⊇ subset-improper	E 69, E 71		15, 16	
⊂ ⊃ subset-proper	E 68, E 70		16, 17	

Note: A blank space indicates that character is not available in that font.

Character	Code Number	Font Widths Font 1	Font 2	Font 3
α alpha	E 01	11	15	
β beta	E 02	13	19	
γ gamma	E 03	11	17	
δ delta	E 04	9	15	
ϵ epsilon	E 05	7	10	
ζ zeta	E 06	8	11	
η eta	E 07	10	16	
θ theta	E 08	10	14	
ι iota	E 09	6	8	
κ kappa	E 10	9	12	
λ lambda	E 11	10	14	
μ mu	E 12	12	17	
ν nu	E 13	9	13	
ξ xi	E 14	10	14	
O omicron	E 15	9	13	
π pi	E 16	12	17	
ρ rho	E 17	10	16	
σ sigma	E 18	12	18	
τ tau	E 19	9	13	
υ upsilon	E 20	9	14	
φ phi	E 21	12	18	
χ chi	E 22	12	17	
Ψ psi	E 23	13	18	
ω omega	E 24	12	18	

Character	Code Number	Font Widths Font 1	Font 2	Font 3
A Alpha	E 25	14	22	
B Beta	E 26	12	18	
Γ Gamma	E 27	11	18	
Δ Delta	E 28	12	19	
E Epsilon	E 29	11	17	
Z Zeta	E 30	10	16	
H Eta	E 31	12	21	
Θ Theta	E 32	12	19	
I Iota	E 33	7	11	
K Kappa	E 34	12	19	
Λ Lambda	E 35	14	19	
M Mu	E 36	15	26	
N Nu	E 37	14	22	
Ξ Xi	E 38	13	18	
O Omicron	E 39	12	19	
Π Pi	E 40	14	21	
P Rho	E 41	11	20	
Σ Sigma	E 42	12	19	
T Tau	E 43	13	20	
Υ Upsilon	E 44	13	20	
Φ Phi	E 45	11	20	
X Chi	E 46	13	21	
Ψ Psi	E 47	15	22	
Ω Omega	E 48	15	19	

Note: A blank space indicates that character is not available in that font.