One Approach to Computer Assisted Letter Design

H. W. Mergler and P. M. Vargo

ITSYLF is an interactive synthesizer of letterforms, which can be used in the design and study of alphabets. It is a computer assisted, operator oriented programming system which allows a typographic designer to enter numeric values through a keyboard and manipulate the characteristics of the letterforms quickly and easily. The alphabet was divided into classes, based on geometric properties of the letters. A set of parameters was derived that allows the construction and manipulation of the letter shapes based on mathematical models of the letters. A set of programs was generated that produces a drawing of the letter which corresponds to the current parameter values. Examples of the effects on the letter shapes of various sets of parameter values are presented for E, A, D, C as well as examples of computer generated serifs and three sets of consistent letterforms that could be used as the basis for several new alphabets.

"Electronics will soon force its claims upon letterforms, and let us hope they will liberate us from the dust of the past." [1]

The art of designing letters is a very old one; the ancestors of modern capital letters may be traced back to the Trajan Column of the Roman Empire.[2] There is no question as to the high degree of skill that must be possessed by letter designers to resolve the myriad problems of letter height, width, the weights of the thick and thin strokes, and serif design. If one investigates an alphabet, it should readily become apparent that there is a tremendous amount of structure and regularity in a fine typeface. The amount of structure might lead one to think about a computer-based system that could exploit it for design purposes.

The most significant use of letters is to convey information by means of the printed word. In the past, at least since the advent of metal type,

1. Hermann Zapf, "The Many Faces of Zapf," *Lithopinion*, III, no. 2 (1968), 59.
2. Fred W. Goudy, *Capitals from the Trajan Column at Rome* (New York: Oxford University Press, 1936).

letterform design has reflected characteristics of the metal; the need to shape the letters in metal or to produce them on a hot-metal composing machine, for example, have been limiting factors. This has led to a class of contemporary letterforms which are suited to letterpress printing. However, for the past 20 years typography and printing have been undergoing significant changes in both technique and philosophy.[3] These changes include such advances as computer controlled hot-metal typesetting, hyphenation and justification programs, page composition, and computer controlled photoelectric typesetting using cathode ray tubes to expose film.[4] While there has been some attempt to develop typefaces which reflect the technology and capabilities of the modern digital computer—such as the American Standards OCR Font [5] or Wim Crouwel's experimental design for an alphabet particularly suited to the requirements of cathode ray tube typesetting [6]—these efforts have not had a significant impact on book, magazine, or newspaper printing. Today, much effort is being devoted to altering typefaces designed for hot-metal composition to make them suitable for computer controlled photocomposition. Perhaps one could draw a parallel between these efforts and Gutenberg's attempt to produce printed matter that looked like handwritten manuscripts. Within a few decades letterforms evolved which reflected the characteristics and properties of the new medium: movable metal type. Little effort is being made to utilize the characteristics of modern data display equipment to design letterforms which reflect the current capabilities and tools of the printing industry.

ITSYLF, an Interactive Synthesizer of Letterforms, is a typographically oriented man-machine system. It represents an attempt to use the data manipulation capabilities of modern computers to support the efforts of the typographic designer. ITSYLF results from a synthesis of two different trends in an effort to develop a system that will allow a typographic designer to quickly and easily manipulate the letterforms based on his

3. Kelber and Schlesinger, *Union Printers and Controlled Automation* (New York: Free Press, 1967).
4. "Latest Word in Printing Spells New Electronics Market," *Electronics,* XL (May 29, 1967), 137.
5. *U.S.A. Standard Character Set for Optical Character Recognition* (New York: U.S.A. Standards Institute, 1967).
6. Wim Crouwel, *New Alphabet: an Introduction for a Programmed Typography* (Hilversum, Holland: Steendrukkerij de Jong & Co., 1967), booklet.

concepts of them. At the same time, ITSYLF relieves him of some of the graphical bookkeeping—such as drawing lines and maintaining appropriate widths and heights—which is essential to designing letters that are to be compatible with one another.

The two trends referred to above are the expanding use of computer controlled photocomposition in the printing industry and the development of computer graphics and computer assisted design in engineering. ITSYLF will enable a designer to rapidly synthesize new and different letterforms for design purposes or to approximate known hot-metal faces to investigate their characteristics. It can also be used to study the effects a change of parameters would have on a new set of letterforms, either on one letter or on a complete alphabet. ITSYLF has a further advantage beyond the ease with which letterforms may be manipulated in that the letters are generated using a digital medium, a core memory, which is ideally suited for use with modern CRT display and photocomposition systems as opposed to a continuous paper and pencil medium which must then be converted to a digital representation.

ITSYLF has been restricted to the generation of 24 roman capital letters. (The Q and J have not been considered for reasons to be elucidated later.) It consists of 24 sans-serif letter generating routines, a monitor system, and various serif generating and letter drawing routines. The letter generating routines are extremely flexible and, based on parameters entered by either the operator or the automatic executive system, can produce letters having many different characteristics. When running in a manual mode, the operator may generate individual letters which are completely dissimilar to one another. When running under control of the automatic executive system, parameters for all 23 other letters are calculated based on values input by the operator for the letter E. (The E has been chosen as a key letter as it is one of the commonest letters in the English language.) A consistent set of letters is then automatically synthesized and drawn. The requirement of consistency is of extreme importance, for, as observed by Fred Goudy, "The making of a type design is quite easy . . . one has only to think of a letter and draw about the thought. . . . The great difficulty lies in thinking of 25 other letters to go with it in complete harmony." [7]

7. *Design of Types* (Adirondack Club of Printing House Craftsmen, 1941).

This leads one to a definition of the activity that ITSYLF, along with a typographic designer, engage in. This is digital letter design, which is defined to be the synthesis of characters, either singly or as members of a set, all of which are consistent with one another. This is somewhat different from the definition proposed by M. V. Mathews for digital type design: "Digital type design consists in determining the coordinates of the vectors which form the image of the letter." [8] Mathews was primarily concerned in his definition with the replication of hot-metal faces on cathode ray tubes as opposed to the synthesis of digital letterforms.

There has been much research into the characteristics of letters and alphabets in the past but very little of it has been oriented toward letter synthesis. There has been work done in the areas of legibility,[9] readability,[10] and letter-spacing [11] but the work associated with letter design has been of a highly qualitative nature and, at most, provides a conceptual framework in which to think. To construct a letter generating system, it has been necessary to postulate the existence of a set of parameters that will realistically describe the letter shapes. Then it was necessary to investigate the geometric characteristics of each letter and extract this set of parameters which could be used to specify and describe the letter. The data that were used in deciding on significant parameters and in developing the relationships between the letters came from 18- to 24-point letters photographically enlarged 32 times. It would, of course, have been very desirable to use original drawings of the letters but these were impossible to obtain. The four fonts used were Bodoni Bold, Times Roman, Futura Medium, and Vogue Light. These four fonts were chosen because they are representative of a large number of different fonts and fairly good enlargements could be made.

ITSYLF produces for the designer a picture of the synthesized letter or letters which are drawn on a Cal-Comp plotter either 4-times or 32-times actual size. The 4-times size was a result of available plotter resolution

8. M. V. Mathews, *et al.*, "Three Fonts of Computer-drawn Letters," *The Journal of Typographic Research*, I (October, 1967), 345–356.

9. *Legibility of Alphanumeric Characters and Other Symbols* (Washington, D.C.: U.S. Department of Commerce, 1964).

10. *Ibid.*

11. D. Kindersley, *An Essay in Optical Letter Spacing* (London: Wynken deWorde Society, 1966), booklet.

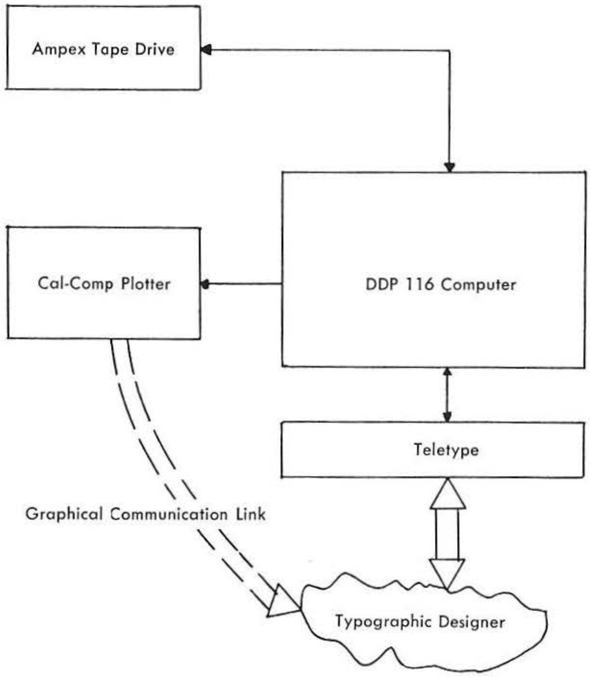
and the necessary size of the sampling interval to achieve adequate reproduction of known fonts. The 32-times size output has the same resolution as the 4-times size, but each of the incremental plotting magnitudes is multiplied by 8. This mode is useful for comparing synthesized letters directly with the photographed originals.

It should be noted that no attempt has been made to investigate the character spacing problem. All characters are arbitrarily centered on the character generation matrix. This is not to imply that the spacing problem is trivial or unimportant. It is neither. The decision has been so made precisely because the spacing problem is quite involved and should be considered as a problem in its own right. This is so even though the parameter values for the letters and the space between them are definitely interrelated. It is the authors' opinion, in fact, that a computer-based spacing algorithm based on the optical spacing system developed by David Kindersley [12] is not only feasible but, coupled with a letter synthesizing scheme such as ITSYLF, would result in a powerful typographic design tool.

System Structure and Characteristics

ITSYLF depends on a very basic assumption about the typographic design process. It assumes that the significant function a letter designer carries out is the making of choices—often based on unknown criteria—concerning the desirability of certain letterform shapes, heights, widths, stroke weights, and serif characteristics—to name a few. This leads to the implication that the drawing of character shapes is necessary to see the results of the design effort, but it is not inherently a part of creative letter design. ITSYLF takes in parameter values that embody the essential characteristics of a letter and does the necessary bookkeeping work to generate and draw the resulting letterform. The programming system does all the quantitative work necessary to generate and draw characters of appropriate heights, widths, and with the necessary stroke thicknesses while leaving the operator free to think about how he wishes to manipulate the letter parameters. ITSYLF runs on what is classified as a small computer system. Available hardware includes 8,000 words of memory, a magnetic tape drive for bulk storage, a Teletype for

12. *Ibid.*



Solid, single arrows indicate paths of electrical communication with the arrowheads showing the direction of data flow.

Figure 1. System hardware and communication paths.

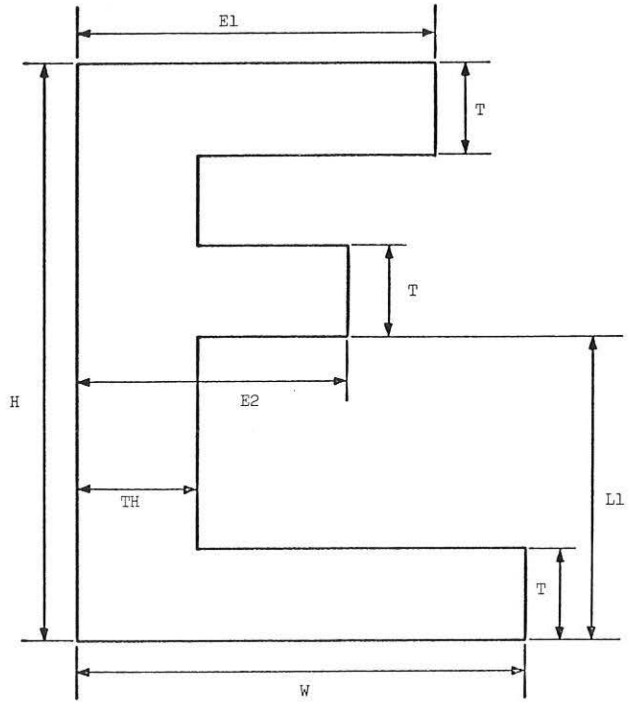
communication to and from the programming system, and a Cal-Comp plotter for graphical output. ITSYLF consists of 24 sans-serif letter generating routines plus assorted control and serif producing programs. (The Q and J seem so similar to the O and I that at this stage they are excluded.) The operator communicates with the systems programs by means of the Teletype. The system is operator oriented and one is able to call various routines for execution, define parameter values, or determine the states of the system simply by entering the appropriate names and values through the Teletype keyboard. Once the name of a program has been entered, the system positions the tape on which all programs are stored, reads the program into memory, and starts it automatically. There is automatic checking of the inputs to be sure that they are correct and may be understood by the system. If errors are found, diagnostic messages are typed out on the Teletype, and the system waits for a correct input to be entered by the operator.

Figure 1 is a block diagram of the system hardware and the significant communication paths. As can be seen, there is a visual, graphical communication link between the plotter output and the designer. The other communication paths are serial, symbol oriented, and are used to transmit formal messages between the components of the running system or between the operator and the system. The graphical link is the path by which the system loop is closed through the operator, and it is on the basis of this graphical feedback data that the designer determines if he is satisfied with the shape of the generated letter. If not, it may quickly be changed by entering a different parameter set for the letter or just changing the offending parameter value. The letter may then be redrawn with this new set of parameters. Characters are represented in the computer's memory by a two-dimensional binary matrix. Initially the matrix, which is 208 x 208 bits, is set to all zeros. The letter generating routines set each bit on the edge or interior of the character being generated to a 1. This basic character shape is then automatically coded to produce a set of instructions which are used to drive the plotter. The matrix size is dictated in part by the available number of words of core memory and partly by the need to generate characters with as small a sample interval as possible. The character generation routines select appropriate rows and columns, and the letters are generated a row at a time.

Letter Generation

Suppose that an operator wishes to design a letter, E, based on some criteria. For example, he may wish to design a letter with equal width strokes or with condensed or expanded characteristics. To do so, it is only necessary that he introduce into the system appropriate values for the parameters of the letter E,which are defined in Figure 2. These are values for the height, width, weight of the thick and thin strokes, length of the top and center horizontal, and the height of the center horizontal from the foot of the letter. Once the necessary values are entered, ITSYLF will produce the corresponding graphical version of the letter. Figure 3 illustrates four different sans-serif versions of the E. (Note that these are drawn four-times actual size.)

If it should happen that the operator does not like the version of the letter that a given set of parameters produces, it is only necessary that he alter the parameters in the direction that seems desirable and have the letter drawn again. Figure 4 illustrates the letter E with all parameters



Letter parameters entered by operator are, E1, E2, H, L1, T, Th, W.

Figure 2. Parameter definitions, letter E.

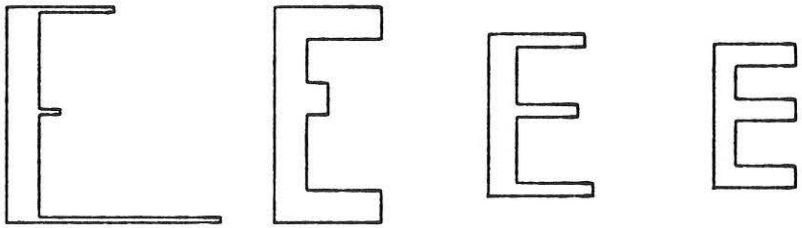


Figure 3. Four sans-serif versions of the letter E.

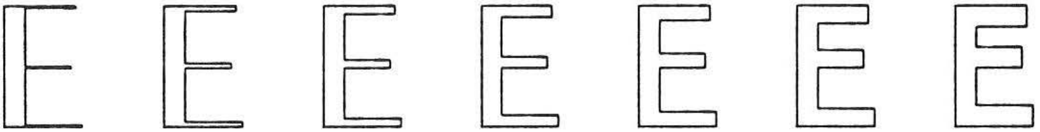


Figure 4. Variation in changes of form of letter E as value of T is increased in increments of four units starting with a value of two units for the left-most E.

fixed except for the weight of the thin stroke (T). It is interesting to note the extreme changes in form that the figure demonstrates even though only one parameter is being manipulated. The total time necessary to generate and draw these versions of the E was under four minutes. The generation itself is almost instantaneous but drawing the letter and moving the magnetic tape to get the necessary programs are rather slow.

Before it was possible to produce a set of letter generating routines, it was necessary to produce a mathematical model for each of the letters. To this end, the alphabet has been divided into classes based on significant geometric properties as follows:

Class 1 letters—E, F, H, I, L, T. These are the most elementary letterforms composed only of horizontal and vertical straight lines.

Class 2 letters—A, K, M, N, V, W, X, Y, Z. This class is composed of letters which have straight lines that are not necessarily horizontal or vertical.

Class 3 letters—B, D, O, P, R, U. These are the most elementary curvilinear letterforms and are composed of both straight and curved strokes.

Class 4 letters—C, G, S. The C, G, S require generation procedures that are much more involved than Class 3 procedures though they are composed of the same variety of strokes.

Class 5 letters—J, Q. The J and Q are classified together because while both have the basic Class 1 and Class 3 forms of the I and O, they also have very free-form tails that significantly alter their appearance.

The models of the letterforms that were used evolved out of an investigation of the geometrical characteristics of the letters of the four type fonts mentioned previously plus some comments concerning the characteristics of the letterforms and their historical background.[13–16] The models are quite flexible and will let the designer investigate a great number of parameter combinations. These models also have the advantage of being easily changed as more becomes known about the letters.

13. E. Weiss, *Design of Lettering* (Pencil Points Press, 1932), p. 9.
14. B. Warde, *Type Faces Old and New* (London: The Bibliographical Society, 1935), p. 138.
15. M. Bigelow, *Alphabets and Design* (San Diego, 1965), p. 41.
16. W. A. Dwiggins, *WAD to RR: a Letter about Designing Type.*

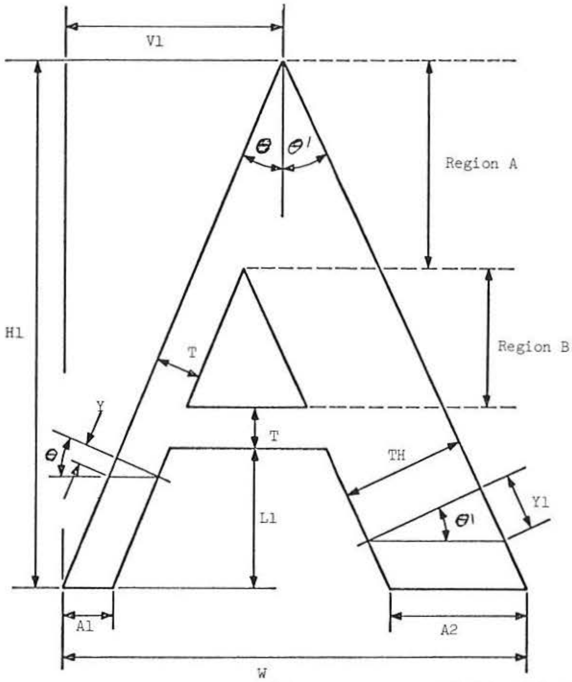
The E (discussed previously) is typical of Class 1 letters and is composed of one vertical and three horizontal strokes. It is generated in the computer's memory sequentially. First the vertical is produced followed by the three horizontals. As an example of the Class 2 letterforms, consider the letter A and its parameter definitions in Figure 5. The A is composed of two slanting strokes and one horizontal stroke. As can be seen from Figure 5, all parameter definitions are linear as opposed to being angular. This is because it is the author's opinion that the effects of altering linear parameters of a two-dimensional shape are much more intuitively obvious than altering an equivalent angular parameter. In the case of the E, there seems to be only one adequate set of parameters. In the case of the A, however, some question might be raised as to the necessity of parameter V1. Based on results from the four measured type fonts, V1 seems to have a value near W/2, but enough variation exists that it seemed desirable to make V1 independent of W. If V1 gets very far from W/2, however, a skewed and rather strange looking letter results. Figure 6 illustrates the effects of radically altering the parameter values of the A. Figure 7 demonstrates for the A the effects of altering the weight of the thin stroke (T) while holding all other parameters constant. Note from Figure 5: the width of the two slanting strokes, T and TH, is the perpendicular width. One of the functions of the letter generating routine for the letter A is to calculate the appropriate horizontal width. This is done by calculating the necessary tangent values based on values of H and V1 and then using Pythagoras' Theorem. The A is generated in one pass rather than a portion at a time as the E is. This is because the actual positioning on any row of the matrix is a function of the distance one is from the foot of the letter.

As an example of a Class 3 letter, consider the D and it's parameter definitions in Figure 8. In order to generate the Class 3 letters, it is necessary to combine straight strokes, whose mathematical model is that of the straight line,

$$Y = MX + B$$

with curved strokes to produce the lobes for B, D, P, R, U and the circular O. The mathematical curve that is used for this function is the superellipse.[17] The superellipse has an equation of the form:

17. "The Superellipse," *Scientific American,* ccxiii (September, 1965), 222.



Letter parameters entered by operator are H1, L1, T, Th, V1, W.
Calculated parameters are, A1, A2, Tan Θ, and Tan Θ '.

Figure 5. Parameter definitions, letter A.

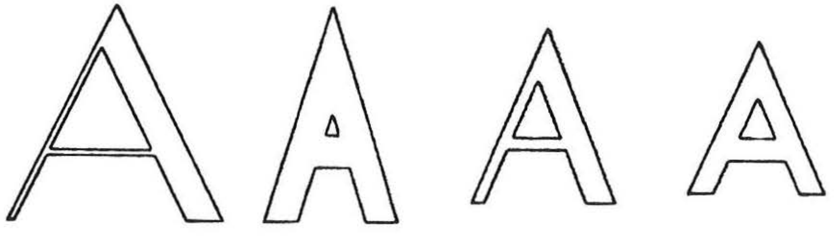
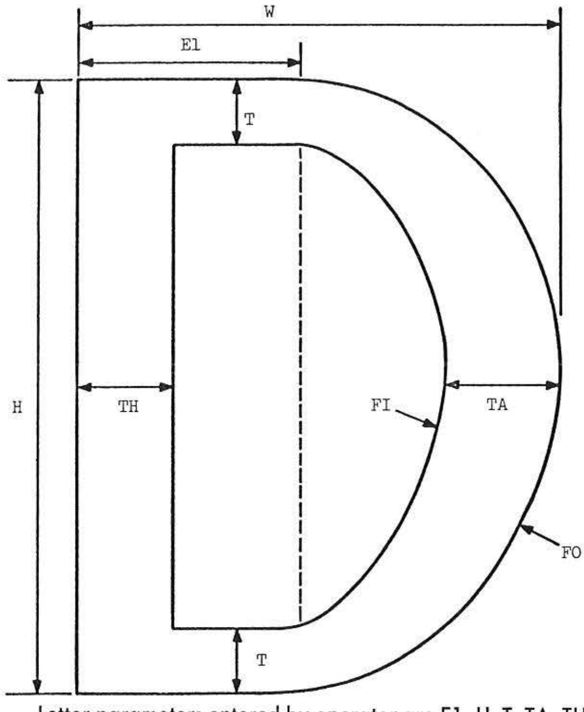


Figure 6. Four sans-serif versions of the letter A.

Figure 7. Variation in changes of form of letter A as value of T is increased in increments of four units starting with a value of two units for the left-most A.



Letter parameters entered by operator are E1, H, T, TA, TH, FO, and FI.
Calculated parameters are a, b, a1, b1.

Figure 8. Parameter definitions, letter D.

$$(X/A)^F + (Y/B)^F = 1$$

For a given A and B, varying F between 2 and 3 produces curves as in Figure 9. As F increases, the curves tend to take on a more square appearance. This curve was chosen because it seemed to approximate quite well the lobes of the letters of the four measured fonts. In the case of the letter D, the squareness coefficient of the interior curve may be adjusted independently of that for the external curve. This has been done to account for a "thinning" phenomena which has been observed on the measured fonts. This phenomena occurs as the exterior curve of the lobe has a value of F less than the interior curve. As a result, one encounters the phenomena displayed in Figure 10 where the interior curve is more square than the exterior curve and the letter appears "thinner" in some portions than one might initially expect. For all Class 3 and Class 4

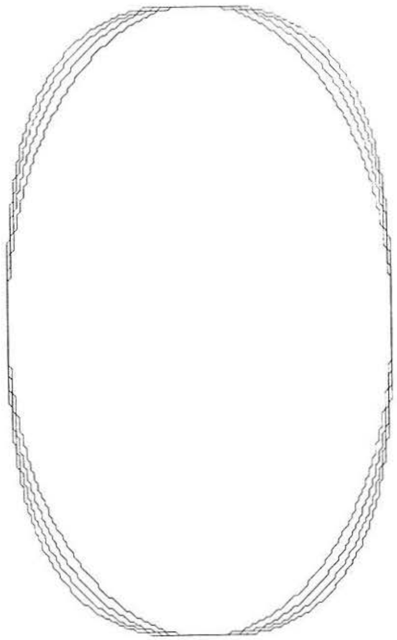


Figure 9.
Superellipses illustrating the effects of increasing F from 2 to 2-3/4 in increments of 1/4 (interior curve has F = 2).

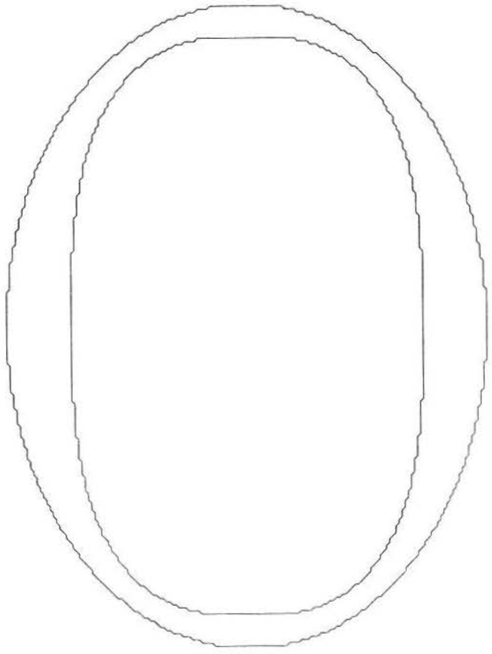
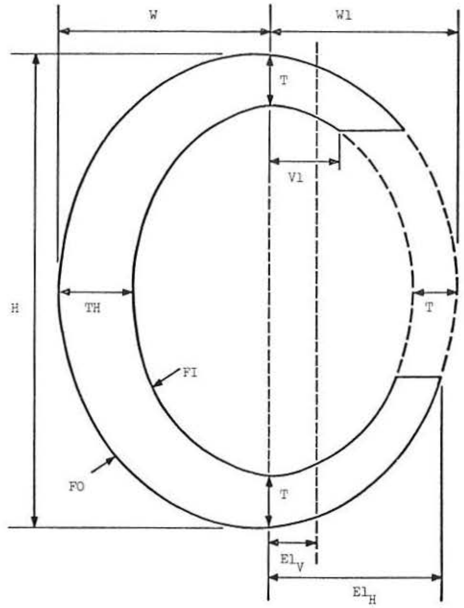


Figure 10.
Letter 0 illustrating "thinning" effect due to interior squareness parameter being greater than external value.



Letter parameters entered by operator are H, T, TH, V1, W, W1, FO, FI, $E1_H$ (value of E1 that might be used if horizontal edges are desired) or $E1_V$ (value of E1 that might be used if vertical edges are desired).

Figure 13. Parameter definitions, letter C.

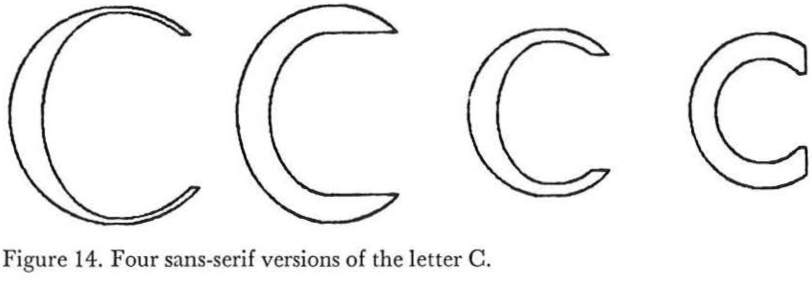


Figure 14. Four sans-serif versions of the letter C.

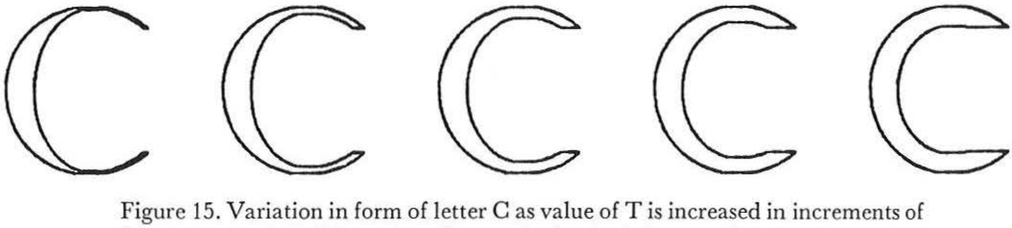


Figure 15. Variation in form of letter C as value of T is increased in increments of four units starting with a value of two units for the left-most C.

As an example of the ability of ITSYLF to approximate a known type font, 18-point Times Roman, consider Figures 16-19. In each case, the filled in letter is a 32-times size enlargement of the printed original. The outline form is an electronically generated, sans-serif version of the letter to the same scale. (They have been reduced in size for printing purposes.) A comparision is rather difficult to make because of the influence the serifs have on the face, but the basic letterforms are quite close with the exception of the C which is not so good.

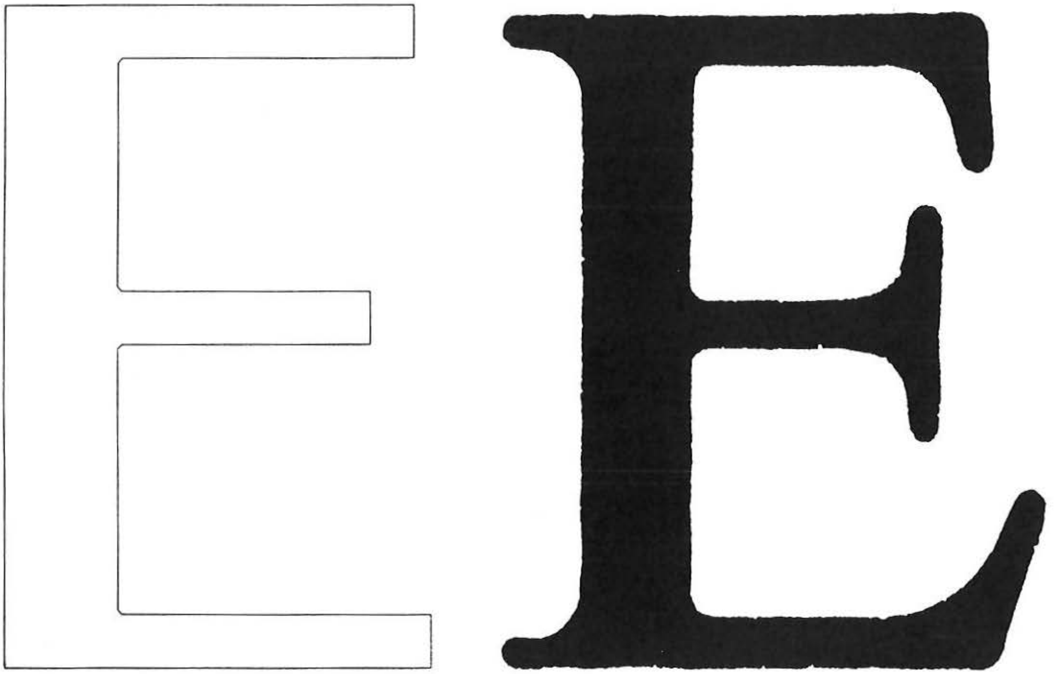


Figure 16. An example of the ability of ITSYLF to approximate a known type font, 18-point Times Roman.

Figures 17-19. Examples of the ability of ITSYLF to approximate a known type font, 18-point Times Roman.

Serif Generation

ITSYLF presently generates two different types of serifs. As illustrated in Figure 20, one is associated with vertical or slanting strokes, the other is associated with horizontal strokes. Parameter values for the height and width of serifs may be entered through the Teletype as with any other parameters. In case more than a square serif is desired, provision has been included to specify two radii, R1 and R2. When these parameters are nonzero, a fillet of appropriate radius is generated once the basic block serif has been formed. At the present time, fillets are only associated with horizontal or vertical strokes and not with slanting ones. This is because of the difficulties of fitting a curve to two nonperpendicular lines. One avenue of possible interest would be to fit a catenary (the equation of a chain suspended only at its ends) at the intersections of the slanting and horizontal strokes. Figure 21 illustrates the effects of serifs on the E, A, D. No serifs are generated for the letter C.

The Automatic Executive System

The purpose of the automatic executive system is to enable a designer to generate 24 consistent letters based on the parameters of one letter. In this case, the letter E has been chosen. The necessary consistency relations have been produced by taking average values of ratios of all significant letter parameters with respect to corresponding parameters for the letter E. The four measured fonts were used to produce the ratios from which average values were drawn. Some of the less significant parameters were not derived from the E as it did not seem necessary. These are usually assigned arbitrarily to zero. Once the parameters for the letter E and a complete set of serif parameters are entered, the automatic executive system may be started. It will generate the 23 other letters and draw two versions of each one. One version will have serifs, the other will not. Three sets of letterforms that were generated this way are illustrated in Figures 22–24. In case some of the suggested letters are not suitable to the designer, that particular letter program may then be called, and the parameters for that letter manipulated to produce the desired shape. To fully benefit from the potential of this program, much more study of the characters is necessary.

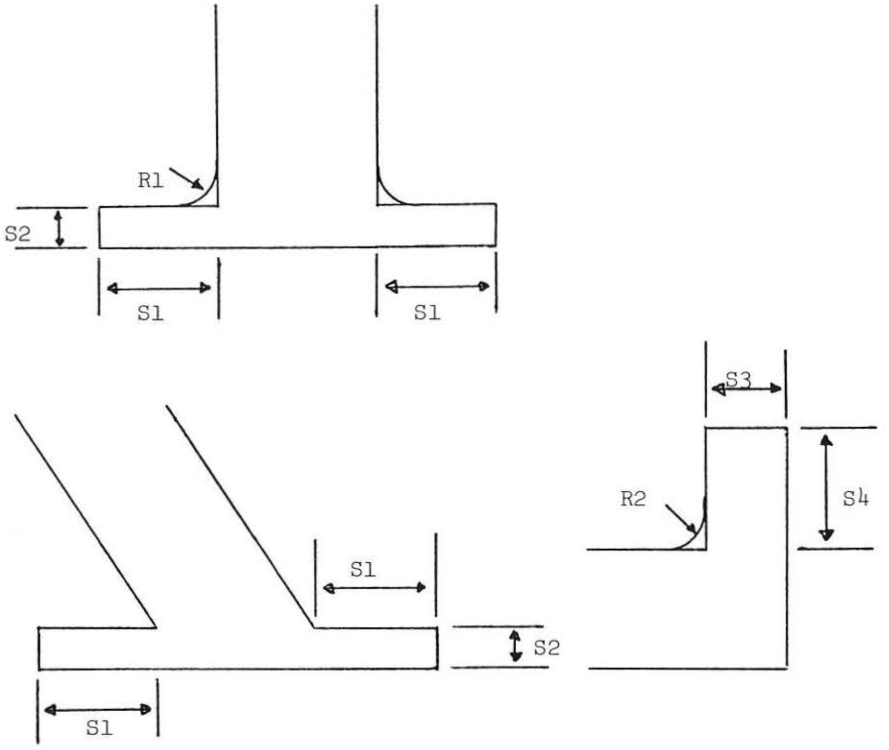


Figure 20. Serif parameter definitions.

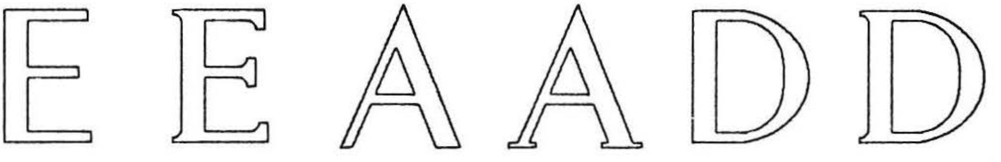


Figure 21. Effects of serifs on E, A, and D.

Following pages:
Figures 22–24. Letterforms generated by Automatic Executive System.

ZZCRR

YYVV

IILL

FFHH

PPTT

NNOUU

DDKK

EEAA

WWXXS

BBGMM


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

Z Z C R R

Y Y V V

I I L L

F F H H

P P T T

N N O U U

D D K K

E E A A

W W X X S

B B G M M

Conclusions

It seems reasonable to conclude, based on the performance of the system, that the postulated set of parameters does exist and may be utilized in conjunction with a set of mathematical models to design aesthetically pleasing characters. ITSYLF, however, represents just a first attempt at computer assisted letter design, and more research will be necessary before a finished system results. Among other problems still to be investigated are the general serif design problem, the general spacing and legibility problem, and further investigations into the properties of the letters to develop more adequate models. Another problem that can now be investigated is the effect on basic alphabets of isolating and modifying specific letterform elements. Additional investigations of known alphabet styles could lead to more than one set of ratios to be used with the Automatic Executive System. The particular set chosen might depend on the ratio of the width of the thick to thin strokes. Depending on exactly what this ratio is, the Automatic Executive System would generate letters of various widths for the same basic width of the E.

ITSYLF suffers from the fact that it is almost too large for the present hardware configuration and, as a result, long waits occur while the tape drive is positioned to read-in the desired program. What is needed is a disk storage system which would allow high-speed loading of the desired programs. Similarily, a graphical display would produce almost instantaneous pictures of the desired letters and eliminate waiting for the plotter to finish drawing them.