

Biographical Note

Charles Cox is pursuing doctoral studies in the Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, where he has been a Western Publishing Company Fellow. He earned the BSEE and MSEE degrees from the Moore School of Electrical Engineering, University of Pennsylvania in 1970 and 1972 respectively. His areas of interest include visual perception and analogue circuit design.

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Barry Blesser is currently an Associate Professor of Electrical Engineering at Massachusetts Institute of Technology where he is engaged in research and teaching. He received his education at MIT where he received his S.B., S.M., and Ph.D. degrees in 1964, 1965, and 1969 respectively.

His current activities are concerned with the perception of auditory and visual stimuli with an emphasis on the recognition of handprinted characters. Other activities include the development of professional audio equipment and the perceptual basis for reverberation.

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Murray Eden is Professor of Electrical Engineering at Massachusetts Institute of Technology. Trained as a physical chemist and applied mathematician, he did research primarily on the modeling of physiological and biophysical processes until he came to MIT in 1959. In the early 50's he began to use generative models for the description of stochastic processes in morphogenesis. After moving to MIT he became interested in studying conventional symbol systems and developed (with Morris Halle) a generative theory of cursive script. With this theory as a basis, computer programs were developed to read standard cursive English. This also led to a series of studies of graphic symbols; hand printed block letters, printed music scores, circuit diagrams. He and his colleagues and students in Cognitive Information Processing Group have continued to study both the theoretical and the pragmatic aspects of pattern recognition. He is currently interested in the relation between pattern recognition and the psychology of perception.





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Analogous forms of the main tools — grammatical and contextual — used in the study of verbal communication are presented for the study of visible communication. The notion of an image context, analogous to linguistic context, is discussed for general two- or three-dimensional scenes. A specific example of image context is graphical context; it is the context embodied by the letters of a type font — all of which are designed with various consistencies among the style and placement of strokes and serifs. A grammar is presented for expressing the consistencies which exist within any one type font. Two sets of rules — one for strokes and one for serifs — are given together with examples of their use. Finally the inter-relationships of this work with that of the type designer is also discussed.

Context

	Character	Physical Attribute "Closure"	Functional Attribute "Closure"	Letter Label
(a)		Open	Open	C
(b)		Open	Closed	O
(c)		Closed	Open	C
(d)		Closed	Closed	O

In an earlier paper, Blesser, et al. (1973) described a technique for formulating a set of underlying descriptors of characters called **functional attributes**.⁴ Whereas physical attributes are those attributes which can be determined directly from measurements made on the physical image, functional attributes are abstract character descriptors, and, as such, do not have, a priori, any invariant relation to one or more physical attributes. In Figure 2, for example, there is shown a series of characters. In Figure 2a the character is physically open and since it is recognized as a "C," it is functionally open. In Figure 2b the character is still physically open; however, since it is recognized as an "O," it is functionally closed. The third character illustrates the reverse situation in which the character, though physically closed, is recognized as a "C"; hence, functionally open. Finally, the fourth character is closed in both senses. The procedure by which the physical representation is translated into the functional interpretation was termed

Figure 2
Four characters, indicating the possible combinations of states for the physical and functional attributes "closure."

⁴ The term "character" will be used to refer to the symbol before recognition has taken place. Once the identity of the symbol has been determined, it will be referred to as a "letter." For a discussion of "The Correlation Hypothesis," a related concept in linguistics, see Watt (1970).

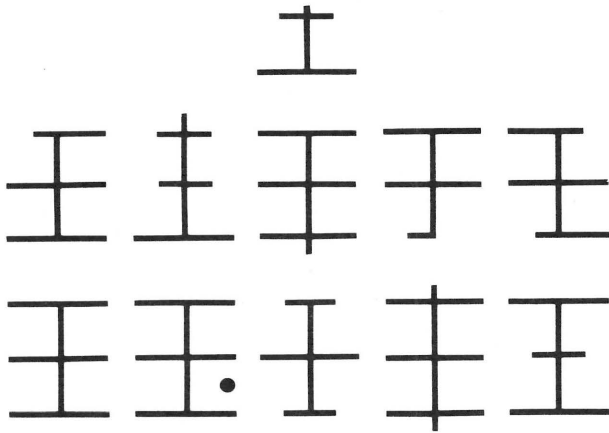


Figure 3
A Chinese ideogram and below it two rows of variations: some of these are sloppy versions of the same ideogram; others are different ideograms. For the "answers" see footnote 6.

graphical context in the paper of Blesser, et al., (1973).

Further work has indicated that it is more appropriate to term these procedures **physical-functional rules** (PFR). There is no unique set of rules applicable to a particular physical character standing in isolation. Their specific form depends upon the context of an image. We use the term **context** to refer to all the factors which can establish constraints on the definitions of the PFR's. One way to view a PFR, then, is as a function of two arguments. One argument is drawn from the set that contains the values of measures of attributes made on the physical image. The other argument is drawn from the set that contains the values of measures made on the various sources of contextual information. Note that these contextual sources will include all information which is relevant to the recognition of images. This will often include information which is not the result of any direct physical measurement of the image, as is the case, for example, with linguistic and cultural context which will be defined below.

With the definition of context so broad, many specific forms of context can be

included under this heading. Semantic and syntactic context, which will be referred to here collectively as **linguistic context**, are two forms which have already been explored; see, for example, Chien and Ribak (1972), Harmon (1972), and Riseman (1971).⁵

Another kind of context might be termed **cultural context**—the context due to one's social or ethnic background. As an example of how powerful this form of context is, consider Figure 3, where a single ideogram from the Chinese

⁵ Linguistic context includes the use of information contained in structure and meaning of strings of characters (with reference to a particular language) so as to rule out strings of letters which could not possibly be part of the language. For example, consider the following sentence: During his stay in the dungeon the prisoner's diet was restricted to _____ and water. The syntax of English implies the blank must be filled with a noun phrase; the semantics of English implies that the most likely noun is "bread." Earlier work, however, made use of linguistic context in a somewhat differ-

ent light. Typically, physical attributes are used to make a first guess at the letter or letters the given character may represent. Linguistic context is then used as a post-processor which maps letter label into letter label. The thrust of the work reported on here views context as that which establishes a link (via the PFRs) between the physical and functional representations. In other words, context will be used here between the character and letter representations, rather than within the letter interpretation.

language is shown at the top and below it a number of variations on this ideogram. Some of these variations result in ideograms which have meanings distinct from the one given at the top of the figure, while other variations result in ideograms which have the same meaning as the given ideogram. Probably most American readers will have difficulty in picking out the ideograms which are just stylistic variations of the given ideogram, whereas few Chinese readers will have such trouble. For the answers to Figure 3, see footnote 6.

Image Context

Of interest in this paper will be a further form of context termed **image context**.⁷ This form of context will refer to all measurements which express the presence of pleonasm⁸ in an image.

As an example of image context, consider a scene containing several different styles of dining room furniture sets; say, in a furniture store display area. The image context of this scene would consist of the types of molding and other routing work, the grain of the wood, and the taper of the table and chair legs,

together with the way these artistic variations are blended together to form distinct sets of furniture. Again, the presence of image context can be appreciated by noting that a chair taken from one dining room set does not "fit" when used to replace a chair in a different style set,⁹ even though it can perform the same function with respect to sitting.

A general, more formal definition of image context is as follows. Image context will be operationally defined to be a set of algorithms; each algorithm will take images of the physical world as input and yield two sets E, R as output. Each member of E will be a description of the pattern present on various subregions of the image. This set, then, will be referred to as the **set of elements**. For example, when working with a modern face type font, members of E would typically include each of the stroke styles and each of the serif designs. Each member of R will consist of relations (or rules) which are satisfied by various spatial arrangements among the members of the set of elements and other portions of the image. This second set will be referred to as the **set of relations**.¹⁰ Again, when working with a modern

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The "Answers" to Figure 3 are as follows. The first and last ideograms in each row are stylistic variations of the given ideogram. The remaining ideograms in each row are different from the given one.

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While admittedly an ultimate pattern recognition machine will incorporate many forms of context, there first must be an understanding of the various forms of context. Hence, the seemingly limited scope of this paper is not intended to belittle the importance of other forms of context; rather, the power and limitations of image context need to be studied and understood as a prerequisite of the overall goal.

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In normal usage, "pleonasm" refers to the use of redundant words in a sentence; specifically, if these redundant words are removed by simply deleting them from a sentence, the meaning of the sentence is unchanged. For example, in the sentence "the man he went fishing," the word "he" can be deleted without altering the meaning of the sentence. In a similar vein, the study here is concerned with those aspects of a character which if removed or reduced to

some neutral form (e.g., remove all serifs and reduce all stroke styles to a single line) do not change the letter label assigned to the character.

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Image context, then, may be viewed as the visual analog of syntactic context in linguistics. For languages, syntactic context takes the elements, e.g., phonemes, of a language and provides relations or rules describing the valid combinations of the elements. Image context takes as elements patterns which occur on various subregions of an image and includes rules which describe the valid relationships among these patterns and the rest of the image. For a discussion of what appears to be the speech domain analog of image context, see the article by Lane (1965), pp. 288-290.

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Strictly speaking, this second set should probably be referred to as a "class,"

face, typical members of R would be the allowable combinations of stroke ends and serifs.

Note that the above definition is not intended to be an alternative definition of a picture grammar or language. Image context is primarily a way of representing the pleonasm of an image and only secondarily its structure. In other words, image context is not concerned so much with the basic structure as with various attributes of a particular style which enable one embodiment of a basic structure to be defined as distinct from another. Thus, image context may be viewed as a portion of a picture grammar. This distinction can perhaps be clarified by considering again the dining room furniture example from above. A picture grammar, as usually defined, would deal with the relationships to be satisfied in order to define the object "chair." Image context would be concerned with relationships which enable one style of chair to be defined as distinct from another, as well as with the commonalities in design that inform the competent observer that a particular table goes with a particular chair.¹¹

Graphical Context

The term image context, as defined above, is an all-encompassing term. The remainder of this paper will be restricted to a discussion of images composed solely of characters. Accordingly, the term, **graphical context**, will refer to all measurements which are derived to express the style and form of the type font. In other words, graphical context is a specialization of image context used when the image consists solely of characters.

Restricting the definition of image context to form a definition of graphical context implies that the criteria for membership in two sets E, R (which comprise the information conveyed by graphical context) need to be correspondingly restricted. It is to be hoped that greater insight into the definition will be obtained by interweaving it with the following example.¹²

Consider the case in which the input image consists entirely of characters from a single roman type font and consider what factors might constitute the graphical context of this font. Since it is a roman font, serifs are intuitively part of

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Whether it is indeed possible to separate the aspects of an object fundamental to its definition from those which are pleonastic is currently being studied for images consisting solely of printed English type font characters.

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Although this example deals with machine-printed characters, graphical context is also applicable to hand-printed characters.

the graphical context. Further, regularities in the shape or design of the serifs are a part of graphical context. To be sure, not all of a font's style is carried by its serifs: the design of the strokes which compose the characters are also part of a font's graphical context. Additionally, there are such factors as the weight — light, medium, or bold; width — condensed, normal, or expanded; x-height and axis. Also, there are the effects that all these factors taken together have on the viewer — e.g., the color and texture of a block of type. The above list is by no means an exhaustive one. However, it is sufficient to suggest that some restriction is necessary in order that the main thrust of the work is not obscured by a myriad of details. Therefore we will restrict the discussion to cover the first two factors only — serifs and stroke thickness. It should be borne in mind that this restriction applies to the discussion below and not to the method in general.

Such a set of attributes, however, is still not enough to describe completely the roles of the serifs and strokes in the graphical context of the font. For example, knowledge of the design of a serif in

a particular font does not, in general, make it possible to tell whether these serifs occur at such places as the top of an "A" or the lower end of a "C." Another set must be formed which contains the relations between each serif and the stroke to which it is joined. Each element will be a relation or rule for predicting the valid arrangements among members of the set of elements for the font under consideration. One way of expressing such a relation is to give it explicitly by stating the locations at which certain serif/stroke combinations occur. Alternately, it may be expressed implicitly by giving a relation or rule which is satisfied by various stroke-serif combinations in particular subregions of the image. Such rules constitute the set R.

To summarize: The objectives of an image context algorithm are to search the image to determine the members of two sets. Members of E are patterns which occur in subregions of the image. Members of R are relations or rules among these patterns and the rest of the image. In the particular subfield termed graphical context, with the restrictions imposed above for this discussion, the

set E will contain a suitable description of each of the various designs of the serifs (if any) and strokes which occur in the characters. The set R will contain the relations present among the serifs and strokes of the characters under consideration.¹³

The aim of the sections to follow is to build up a general framework so that an arbitrary set of characters drawn from any single type font can be analyzed to determine their graphical context. Such a general framework will be approached by studying and developing a particular framework for expressing the graphical context of a few specific type fonts. First, we need to differentiate three sources of variability: those variations due to the style of an isolated character, those variations due to groups of characters, and those variations which might be termed physical noise. The last source of variability will not be discussed in this paper. Further, we choose to restrict our analysis to the single character level, thus variability resulting from forming groups of characters — such as ligatures and letter spacing — will also not be discussed in this paper.

We make no claim that the empirical methods used for determining the graphical context of a given set of characters were consciously used when the characters were created by the type designer.¹⁴ Another point is that no attempt has been made to establish a recognition procedure for identifying the conventional name of the font from which a given sample of characters has been taken; graphical context may include necessary conditions for identifying the font, but it does not necessarily include sufficient conditions. A final point is that no claim of uniqueness for the rules is made; the criteria for choosing the final form of the rules presented below were compactness, completeness, and simplicity. Rules that better fulfill these criteria may be found.

¹³ The definition of graphical context does not imply that each character exhibits all the members of the set E of a given style. For example, one part of the graphical context will often be a serif which is used throughout a type font, but that is not to imply that all characters in that font have serifs. Specifically, O's rarely have serifs.

¹⁴ Evidently, according to Gürtler (1967), when teaching students to draw letters, attention first focuses on the drawing of a couple of representative letters — e.g., n and o in Gürtler's paper. Once these have been mastered, drawing the remaining letters follows quickly. If this approach is valid, it would lend at least indirect support to the implicit existence of these rules.

Type Font Style Rules

Recall from the discussion of graphical context that for the purposes of the present discussion there are at most two factors which cause differences in appearance among printed characters: 1) the markings which occur at such places as the ends of strokes and on corners, and 2) the style of the strokes of which the character is composed. In the formalism presented here, the effects of each of the above categories can be expressed by defining the contributions each category makes to the sets E and R.

First, consider the subsets of E contributed by each category. The most common marking is the serif—a short cross stroke which often occurs at the ends of the main strokes and on the corners of most characters. However, since not all markings can be classified as serifs, particularly when dealing with lowercase characters, it was found useful to adopt the following more general definition of markers. A marker is a portion of a character which, if removed, will not result in a loss of the character's identity, or in the formation of an ambiguity with another character.¹⁵ Suitable descriptions of each marker will form one subset of E. This subset will be referred to as the **set of markers**.

Often the stylistic variations of the strokes take the form of two different stroke thicknesses or widths. Another variation is the use of a combination of decorated and plain strokes. Suitable descriptions of each stroke style will form the other subset of the set of elements, **the set of strokes**.

Clearly the task of expressing the graphical context of any printed character is enormous. The following assumptions and limitations are made to narrow down the task to manageable proportions.

The set E will be assumed to be given. We make this assumption because the determination of the elements is basically a detection question. It is more appropriately discussed when an implementation is under consideration, rather than as part of a theoretical study.

The discussion below will be limited to machine-printed characters. Within this realm there is, conceptually, no restric-

tion on the family from which the type font is drawn. However, only a limited amount of work has been done on type fonts from the swash, script, and 3-D families. The main thrust of the work has dealt with fonts from the roman and sans-serif families. All of the examples presented below will be drawn from one of these two families.

The discussion below will be further limited to uppercase characters (majuscules) because initially they appeared to have greater internal consistency than lowercase characters (minuscules).¹⁶ For example, there are at least four distinct markers for the lowercase of a typical font, whereas there are typically two markers for the uppercase.

¹⁵ Note that a character may have more than one marker. Further note that under this definition all of the tail of a "Q" is not considered a marker because its complete removal would result in an "O."

¹⁶ Ongoing research has indicated that this is not necessarily the case.

The set of strokes will be limited to at most two members; only a few type fonts have been found to date which use more than two different stroke styles. For ease of reference, when two distinct stroke styles are required, they will be given the generic titles of thick and thin. When the stroke styles do indeed come in two physically different thicknesses, the generic titles will take on their usual interpretation.¹⁷ However, stroke combinations such as plain, decorated; single, combination; will also be assigned the appropriate **thick, thin** designation.

The set of markers will similarly be limited primarily, but not exclusively, to two members. A description of the members in this set is a bit more involved than the description of members of the stroke set. The discussion of the marker set will be included in the section below entitled Marker Placement Rules.

In the remainder of this paper we will deal with machine-printed, uppercase characters composed of at most two stroke styles and taken from the roman or sans-serif families. As the set of elements will be assumed given, the objectives will be to determine members of the set of relations, R . It was found convenient to express the required relations implicitly in the form of rules.

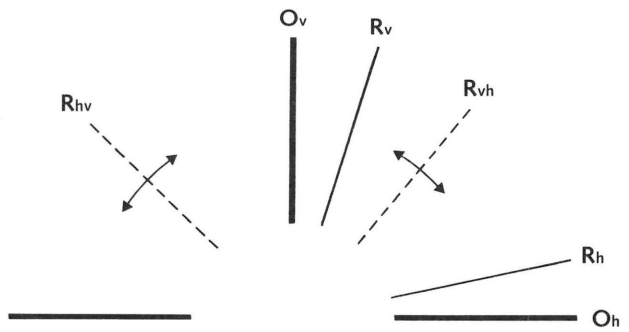
Stroke Style Rules

The rules for establishing the style of each stroke will use the coordinate system shown in Figure 4. The use of two sets of orientations provides the flexibility needed to deal with skewed type fonts, as is the case with italics. The orientations suggested by such large-scale phenomena as the outline of the page or the run of the type will be referred to as **objective orientations**; objective vertical, O_V , and objective horizontal, O_H , etc. The orientations defined by the individual characters themselves will be referred to as relative orientations; relative vertical, R_V , and relative horizontal, R_H , etc. As shown in the figure, lines oriented between R_V and R_H are assigned orientations R_{VH} or R_{HV} .

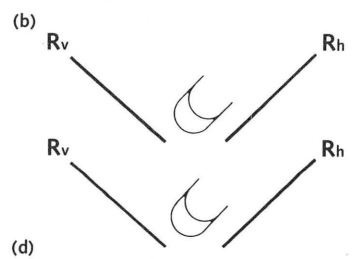
Since the relative orientations are tied directly to the characters and it is the character strokes that are of interest, it might seem that defining the objective orientations is superfluous. Indeed, the objective orientations need to be specified only if the identity of the characters is not available a priori. Without knowledge of either the character identity or the objective orientations, more than

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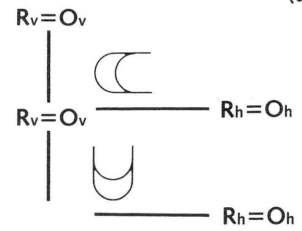
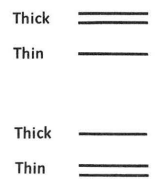
This naming convention was adopted to make the rules more readily comprehensible. However, it will be seen that the rules themselves determine which of the strokes present are assigned which name. Hence, it is possible that in some type fonts the physically thick strokes will be referred to as thin in the rules, and vice versa.



(a)



(d)



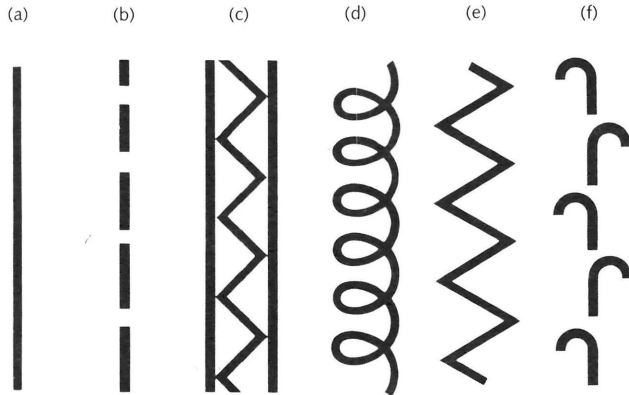
(c)

one meaningful assignment of relative orientations may be made. Subsequently, then, more than one character stroke style assignment can arise. For example, suppose it is not known whether the character shown in Figure 5a is a "C" or a "U," nor are the objective orientations O_v and O_h known. Then, as shown in Figure 5b, two meaningful assignments of the relative orientations R_v and R_h are possible — depending on whether the character is interpreted as representing the letter "C" or the letter "U." For convenience, the two relative orientation assignments may be rotated so that they each line up with the objective orientations defined by the page, as has been done in Figure 5c. Finally, by stroke style rule 3 (which is presented below), the two distinct style assignments in Figure 5d are possible.

Figure 4
Orientation conventions for stroke style rules. Objective orientations are denoted by "O"; relative orientations are denoted by "R."

Figure 5
Example of a problem which can arise if neither the character identity nor the objective orientations are known: a) unknown character, b) two relative orientation assignments, c) assignment of relative orientation to objective orientations of this page, d) stroke assignments consistent with stroke rules.

In the rules below the terms "straight strokes" and "curved strokes" are used in a sense broader than those conventionally associated with these terms; hence, definitions are needed for these terms also. The necessary definitions may be based on the terms "orientation" and "thickness" already defined. A **curved stroke** is a stroke whose thickness along any portion of its extent depends upon the orientation of that portion. On the other hand, a **straight stroke** is a stroke with a single orientation along its entire extent, and hence it has a single thickness. Geometrically straight strokes readily fulfill this extended notion of straight. In addition, this definition allows strokes such as those shown in Figure 6 to be included in a category of straight strokes. Note also that a straight stroke may take on either one of the two styles — thick or thin — along its extent.



With the above background, the **stroke style rules** can be given; they are to be applied in the order listed.

Main Stroke Style Rules

1. Every letter has at least one thick stroke.
2. Two or more thick strokes never meet.
3. Straight strokes with orientation R_H are always thin.
4.
 - i. Curved strokes are thin where they have orientation R_H .
 - ii. Curved strokes are thick where they have orientation R_V .
5.
 - i. Straight strokes with orientation R_{HV} are always thick.
 - ii. Straight strokes with orientation R_{VH} are thin (unless this would violate rule 1, in which case they are thick).
6. Straight strokes with orientation R_V are thick (unless this would violate rule 2, in which case they are thin).

In addition, the following two conventions are adopted when applying the rules:

- i. The basic structure of the letter S is Σ .
- ii. The basic structure of the letter Y is Υ .

Figure 6
Typical straight strokes.

which it is attached. There may be any number of secondary markers, although most frequently there will be only two of these. These secondary markers usually occur at one place in an entire font. Typically, one location of a secondary marker will be the bottom of a "J"; another secondary marker typically occurs on the bottom right leg of the "R." Should additional secondary markers be required, they may be added to the marker set—provided, of course, that rules appropriate for their use are added to the set of marker rules. Also, in some fonts, degeneracies may occur in which one or more of the distinct markers listed above take on the same design. Clearly, this causes no problems with the rules. Further, the rules have the ability to modify the appearance of a marker. For example, the most common modification will be the removal of a portion of a marker.

With the above as background the **marker placement rules** can now be given. As with the stroke style rules, it was found convenient to formulate the set of marker rules in terms of main and dialect rules. Also as before, when the dialect rules are used, they override conventions established by the main rules.

Main Marker Placement Rules

1. All stroke ends have markers;
 - i. strokes with orientation R_H (including curve stroke ends) receive a rounded marker;
 - ii. strokes with orientation R_V , R_{VH} , or R_{HV} receive a square marker.
2. All strokes with orientation R_V terminating in a corner receive a square marker.
3. Markers on the right leg of the "R" and the bottom of the "J" are secondary.

Dialect Marker Placement Rules

1. Markers on horizontal stroke ends (including curve stroke ends) do not extend beyond the run of the type.
2. Markers on corners composed of one R_{HV} (R_{VH}) stroke extend only to the left (right) of the vertical stroke.

3. Markers on curve stroke ends extend only to the left (where left is determined by standing on the stroke and facing the end).
4. Markers on all thin strokes are rounded markers.
5. A marker on the lower end of the "C"
 - i. extends only to the right
 - ii. is not present.
6. Of the markers on the corners of the "N"
 - i. the one on the lower right corner is not present
 - ii. neither marker is present.
7. There is a secondary marker on the top of the "A."
8. There is a secondary marker on the middle corner of the "W."

(a) ABCDEFGHIJKL
 MNOPQRSTUVWXYZ
 XYZ

(b) ABCDEFGHIJKL
 MNOPQRSTU
 VWXYZ

(c) ABCDEFGHIJKLMN
 OPQRSTUVWXYZ

For the type font shown in Figure 9a, in addition to the main rules, dialect rules 1, 2, 3, 5-ii, 6-i are in effect. In contrast, for the type font shown in Figure 9b, only dialect rule 6-ii is in effect. Finally, for the type font shown in Figure 9c, dialect rules 1, 2, 3, 4, 5-ii, 6-i are in effect.

After reading all the rules, the alert reader may speculate that there are "deeper" rules linking the two sets of rules given here. One such set might be: 1) Thin strokes take rounded markers, thick strokes take square markers; 2) where thick and thin strokes meet, the thick stroke determines the style of marker. Indeed, such rules may exist; however, a comparison of Figure 1-iii and 1-vi indicates that these deeper rules are more subtle than the example given here.

Figure 9

The type fonts a) Times New Roman, b) Weiss Initials Series III, and c) Linotype Memphis Light whose marker rules are given in the text.

Conclusion

Two relatively compact sets of grammarlike rules have been developed for representing the graphical context of roman or sans-serif characters. The existence of these rules may yield some insight into the framework within which type designers have been working.

In order to appreciate this point, recall the large variety among type fonts resulting from the design/placement of strokes and serifs. These variations are describable via the appropriate combination of main and dialect rules. But what is the distinction between them? A main rule is one which pertains to all or a majority of the type fonts considered; a dialect rule describes a variation of the main rule which is brought into effect for specific type fonts. Consider now the number of rules in each set: there are seven main rules, together with one dialect rule for stroke placement; there are three main rules and eight dialect rules for marker placement. The large ratio of main to dialect rules in the case of stroke rules suggests that almost all fonts **have the same relative arrangement** of thick and thin strokes. **On the other hand**, the small ratio of main to dialect marker rules suggests that an appreciable variability exists among type fonts with respect to marker placement.

Let us return now to a consideration of the inferences about type design which can be drawn from this work. In the case of strokes, the rules suggest that when the type designer includes two stroke designs in his font he focuses on the creation of two stroke designs (generically referred to in this paper as thick and thin) but does not tamper with the relative arrangement²⁰ of the two stroke styles within a letter. For markers, the rules suggest that the designer feels himself free not only to design the markers themselves but, also, to prescribe their allowable placements. Note, however, that the number of main marker rules is not zero. Hence, the role of the type designer in marker placement is one of modifying a basic pattern — working within a basic set of rules to achieve an esthetically coherent whole.

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"Arrangement" is used here, rather than "Placement," because the rules do not cover, for example, exactly where the center horizontal stroke on an "E" intersects the main vertical stroke. Instead, the rules point out the allowed combinations of thick and thin — in this "E" example both strokes cannot be thick, etc.

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Chapter 5.

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