that despite rules, they will infuse more life, energy and grace into their figures than will another no matter how good a painter he may be. I repeat, then, that the possibility of study in these capitals is so limitless that one should not attempt to lay down precise rules about them or any other matter which someone, as I have shown by my example, could surpass in grace and beauty.

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Why Serifs are Important: the Perception of Small Print

David Owen Robinson, Michael Abbamonte, and Selby H. Evans

The use of serif type styles has continued to dominate printing since the introduction of sans-serif type a century and a half ago. Several theories are considered to account for the continued popularity of the older typefaces. It is suggested that the neurological structure of the human visual system benefits from serifs in the preservation of the main features of letters during neural processing. A computer simulation of visual processing supports this theory, and suggestions are made concerning the function of serifs in letters of different sizes.

Sans-serif typefaces first appeared in the 1830's and were considerably developed earlier in this century. Since there can be no doubt that **H** conveys the same information to literate humans as **H**, it seems strange that the older styles with serifs have been highly resistant to extinction. Because we can perceive each letter without the little additions at the end of their component lines, the continued use of serifs appears at best only decorative and at worst merely superstitious. However, a glance at a selection of journals and books shows that sans-serif type styles do not appear in nearly as many examples as do typefaces with serifs.

Poulton (1964) compared three sans-serif styles of printing with three serif styles in a study of the efficiency of labelling drugs. He found no effective difference between the groups, although Gill Sans was more legible than Univers or Monotype Grotesque 215. Tinker (1963) compared ten different type styles for legibility, including one sans serif—Kabel Light. He found that this type style was read as rapidly as the others but that "readers did not prefer it" and it was placed ninth out of ten for judged legibility. Dowding (1957) suggested that sans serifs are most difficult to read and further commented: "It has been calculated that when the same piece of 'copy' is set in two different types—an old face and a sans serif—that 7½% more time is needed to read the latter."

Unless we are prepared to believe that preference for serif styles of type is merely a matter of aesthetics, then psychology ought to be able to offer some convincing explanation for the survival of older type styles. The most obvious explanation is that the choice of typefaces is merely a matter of conditioning. That is, people who choose typefaces for books and magazines were brought up on serif styles and so are more likely to choose them rather than the newer type styles. However, if that argument had any validity, the draft of this article would not have been written in ballpoint script but with a quill pen!

A more sophisticated theory would be that the serifs increase the horizontal continuity of a line of type. However, it does not appear subjectively more difficult to distinguish the lines in a block of sans-serif print. Furthermore, since adults only make a few eye fixations in reading each average-length line of print, it seems unlikely that the continuity from one letter to the next should be an important factor in legibility and reader-preference.

An alternative theory is that one should expect serif-form letters to convey more information to readers because there are more lines present in each letter than in equivalent sans-serif forms. Against this, it could be argued that serifs do, in fact, detract from the information conveyed by each major component line of a letter by adding "noise" to the visual stimulus. In other words, if letters are perceived in terms of their component lines, the addition of serifs is as useful as scattering soot across a page of sans-serif print.

The explanation which this article proposes depends on the physiological structure of the human visual system. Light falling on the retina excites photoreceptors, and, because there are many millions of these in each eye, even a line which is perceived as being very thin may fall across a band which is several receptors in width. The retina is connected to the visual cortex of the brain by the optic nerve. There are not enough "telephone lines" in this communications link for each receptor to be directly connected to the cortex, and it has long been known in physiology that the receptors do not combine in a simple additive manner.

Using the technique of single-cell recording—implanting microelectrodes into nerve cells and monitoring the activity—the visual systems of a number of animals have been studied. These investigations have included work on the frog, the pigeon, and the cat. In their

article "What the Frog's Eye Tells the Frog's Brain" Lettvin, Maturana, McCulloch, and Pitts (1959) reported that the information transmitted from the frog's retina to its brain concerns the detection of a number of very simple features in the frog's environment, such as a moving bug or an overall darkening due to the shadow of a predator. The pigeon's retina detects straight horizontal lines, codes this information neurologically, and sends it to the cortex. A large part of the literature on the topic has resulted from the research of Hubel and Wiesel working with cats. They have shown that the visual system of the cat includes several types of feature detectors: spot detectors, line detectors, edge detectors, and corner detectors. A spot detector "fires" only if a group of receptors in a small spot are stimulated, while most of those in a ring round the spot are left unstimulated—an "on-center field" or, vice versa, an "off-center field." A line detector responds when a straight line appears in a particular part of the retina. There are intuitive reasons to believe, and some non-physiological data (Schoenberg, Katz and Mayzner, 1970) to confirm, that the visual system of human beings is organized in the same way.

A Model of Human Visual Processing

A digital computer model of "Hubel and Wiesel line detectors" was reported by Evans, Hoffman, Arnoult, and Zinser (1968) who showed that such a system was efficient in retrieving degraded (i.e., "dirty") patterns. The firing of neural components was modeled by numbers and the way in which component parts of the visual system interact and join together was simulated by multiplication and addition. It is possible to convert the results of these processes into meaningful pictures in computer print out. In another test of the model by the present authors (in preparation) the computer program was shown to imitate human behavior in the perception of geometric illusions. The model made mis-estimations of the lengths of lines in these figures in just the same way as the human visual system.

The Model Applied to Letters

The digital computer model of human visual processing was applied to letterforms with serifs, and without serifs, as a test of a line-detector explanation of the importance of serifs which may be stated as

T T E E

f f h h

Figure 1. The stimuli letters used in the experiment. These IBM Selectric characters were transformed into 48 × 48 matrices suitable for digital computer input.

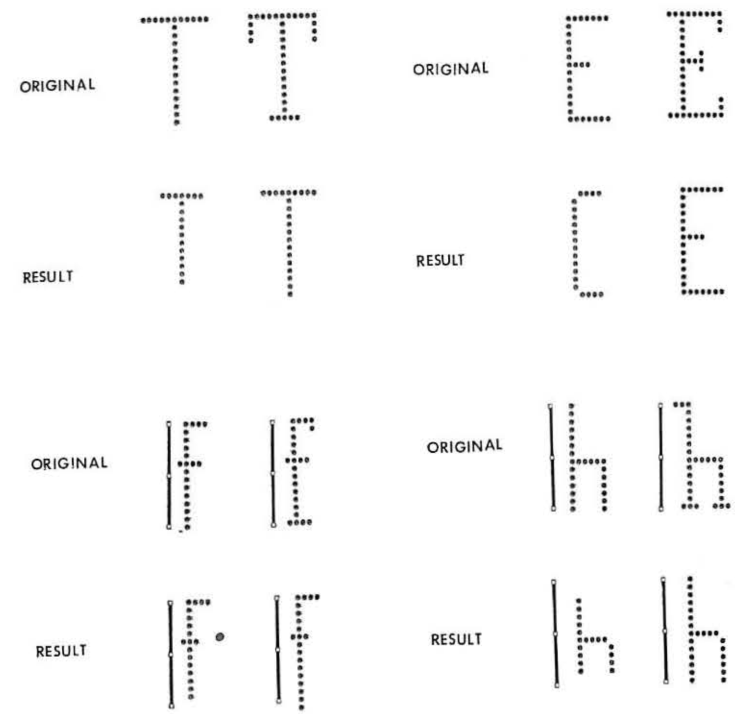
follows: "Serifs are important in the perception of small letters by humans. They react with the line detectors of the visual system with the component lines of letters. The component lines of letters are made easier to see when the letters are of serif form."

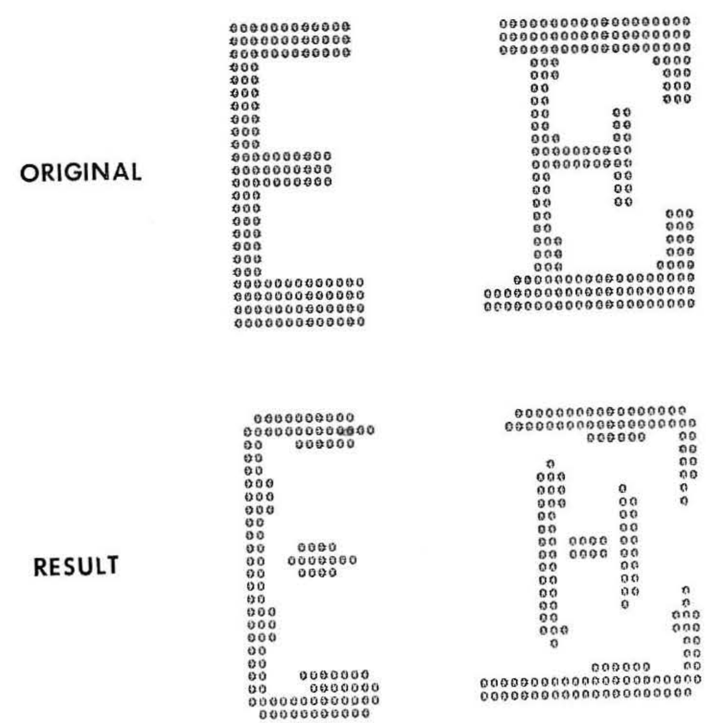
The letters used were E, T, f and h in serif and sans-serif forms with corresponding examples within each of two letter size groups having exactly the same height, width, and line thickness. The examples were based on two IBM Selectric typewriter faces—Courier (serif) and Artisan (sans serif) (Fig. 1). The input to the computer was in the form of a 48 × 48 matrix and the operators which are the part of the model which imitates human visual feature detectors are matrices of size 5 × 5. The relative sizes of the input pattern and of the operators were chosen on the basis of neurological and psychophysical data. Of the two sizes of letter used, the smaller corresponds to the images formed on the retina by ordinary bookprint held at a comfortable reading distance, and the larger examples were nearly twice as high and were of three times greater line thickness. The stimuli letters were submitted and, to each one, a "spot operator" was applied. In effect,

OPPOSITE

Figure 2. The results of applying the computer model of the line detectors of the human visual system to small letters without serifs (the left of each pair) and with serifs (the right of each pair).

Figure 3. The results of applying the computer model of the line detectors of the human visual system to large letters, with and without serifs.





this instructs the computer "Look at this picture: Where are there printed areas?" The results of this operation were stored on tape and horizontal and vertical line operators were then applied to these resultant pictures. This is equivalent to the instruction "What horizontal and vertical lines do you see in these pictures?" The results of these two operations were printed out, which is like asking the computer to draw what it has seen.

Results

In Figure 2 it is clearly shown that serifs perform an important function in preserving the original image of a small letter in a perceptual system with horizontal and vertical line detectors. The image of the sans-serif E is considerably degraded, whereas the corresponding serif-form letter is perceived without deformation of the major component lines. Standard reference lines of equal length placed alongside each of the lower-case letters show how the height of sans-serif forms is perceived as less than original, whereas the serif forms are perceived without decrement of the main lines. The difference between the two type styles is least in the case of the letter f; however, this is an expected result since the difference between the original figures is very small.

Serifs are not useful when large letters are presented to a line detector system, as shown in Figure 3. When the line width of the image of the letters is greater than the width of the detection, serifs do not help to preserve the main features of a letter. One example is given here; similar results apply to three other letter pairs which were submitted to the same operators.

Discussion

Serifs are only important in letters which are small enough to be perceived by line detectors: most ordinary print in the texts of books, periodicals, and typewritten material. Larger and/or thicker letters are probably perceived by a different part of the system—the edge detectors. However, the image of large letters *are* of line-form when viewed from a distance. Serifs are useful not only when the letterforms are physically small, but may also be functional when large letters form a small image on the retina—as, for example, when a billboard is seen from far away.

The line-detector theory of the importance of serifs in the perception of small print can be supported by three observations. As mentioned above, a sans-serif style was not preferred by readers when compared with serif styles and the examples used were of "small letter" size. Further, when one perceives small letters, one is not necessarily aware of the serifs. They can be detected on closer examination either by bringing the material closer to the eye (thus increasing the size of the retinal image) or by selectively attending to line detectors of finer resolution. The line detectors of the visual system are in a range of sizes, and it seems probable that one can "tune-in" to a certain size of detector when the situation demands—a kind of neurological fine tuning of the receptor system. Finally, the degradation of the neural image of sans-serif letters does not have a disasterous effect on legibility, as might be supposed from the sans-serif examples in Figure 2, because of the considerable influence of context. For example, if one erases one third of the letters in a sentence it is still readable: An *xa*pl* of* se*te*ce *it* mi*si*g l*tt*rs.

If the computer model has any validity as an imitation of the human visual system, then one may conclude that serifs are important in preserving the image of small letters when they are represented in the neurological structure of the visual system.

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Note: This research was supported by the Department of Defense, Project THEMIS Contract (DAAD05-68-C-0176), under the Department of Army to the Institute for the Study of Cognitive Systems. Further reproduction is authorized to satisfy needs of the U.S. Government.