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Editor's note

Visible Language has a long history of special interest in computer-assisted design of letterforms. A few months after the first issue appeared in January 1967 I walked across the street from my office to the Department of Computer Science at Case Western Reserve University to see if I could arouse any interest in research on the design of typefaces. Graduate student Paul Vargo was indeed interested and under the direction of his faculty advisor, Harry Mergler, produced as his doctoral dissertation the first computer system for parametric letter design. The results were published in this journal (then *The Journal of Typographic Research)* the following year. It was an introductory study and handicapped by equipment limitations of the mid-1960s. In essence, it was an idea whose time had not yet come.

Fourteen years later — in early 1981 — I walked across the street again to meet and talk with Donald Knuth about Meta-Font. By coincidence, Knuth is an alumnus of Case Western Reserve University but was graduated years before Paul Vargo and unaware of his research. I suggested to Knuth that when he was ready to present his ideas to the graphic design audience, he should use the pages of *Visible Language.* He agreed, and "The Concept of a Meta-Font" was published earlier this year.

It occurred to the editors that it might be valuable to follow-up publication with a survey of those most knowledgeable and most experienced in type font generation, asking for reactions and ideas on the meta-font concept and/or on computer-assisted letter design in general.

The article/response by Douglas R. Hofstadter which begins on the opposite page is followed by letters from type designers, graphic designers, and others in the graphic arts field — with a final response from Donald Knuth. The editors thank all of the respondents for their thoughtful replies. The lack of concensus at this stage of developing the meta-font concept is most heartening!

A few copies of the issues containing Knuth's article (Winter 1982) and the Mergler/Vargo article (Autumn 1968) are still available. To order, see the previous page.

M.E.W.

Metafont, Metamathematics, and Metaphysics

Comments on Donald Knuth's Article "The Concept of a Meta-Font"

Douglas R. Hofstadter

It is argued that readers are likely to carry away from Donald Knuth's article "The Concept of a Meta-Font" a falsely optimistic view of the extent to which the design of typefaces and letterforms can be mechanized through an approach depending on describing letterforms by specifying the settings of a large number of parameters. Through a comparison to mathematical logic, it is argued that no such set of parameters can capture the essence of any semantic category. Some different ways of thinking about the problem of the "spirit" residing behind any letterform are suggested, connecting to current research issues in the field of artificial intelligence.

The "Mathematization of Categories" and Metamathematics

Donald Knuth has spent the past several years working on a system allowing him to control many aspects of the design of his forthcoming books—from the typesetting and layout down to the very shapes of the letters! Never has an author had anything remotely like this power to control the final appearance of his or her work. Knuth's TEX typesetting system has become well-known and available in many countries around the world. By contrast, his Metafont system for designing families of typefaces has not become as well known or as available.

In his article "The Concept of a Meta-font" [Knuth 82], Knuth sets forth for the first time the underlying philosophy of Metafont, as well as some of its products. Not only is the concept exciting and clearly well executed, but in my opinion the article is charmingly written as well. However, despite my overall enthusiasm for Knuth's idea and article, there are some points in it that I feel might be taken wrongly by many readers, and since they are points that touch close to my deepest interests in artificial intelligence and esthetic theory, I felt compelled to make some comments to clarify certain important issues raised by "The Concept of a Meta-font".

Although his article is primarily about letterforms, not philosophy, Knuth holds out in it a philosophically tantalizing prospect for us: that with the arrival of computers, we can now approach the vision of a unification of all typefaces. This can be broken down into two ideas: (1) that underneath all "A" 's there is just one grand, ultimate abstraction

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that can be captured in a finitely parametrizable computational structure–a "software machine" with a finite number of "tunable knobs" (we could say "degrees of freedom" or "parameters," if we wished to be more dignified); and (2) that every conceivable particular "A" is just a product of this machine with its knobs set at specific values.

Beyond the world of letterforms, Knuth's vision extends to what I shall call the "mathematization of categories": the idea that any abstraction or Platonic concept can be so captured–i.e., as a software machine with a finite number of knobs. (For more on this notion, see [Hofstadter 82b].) Knuth gives only a couple of examples–those of the "meta-waltz" and the "meta-shoe"–but by implication one can imagine a "meta-chair," a "meta-person," and so forth.

This is perhaps carrying Knuth's vision further than he ever intended. Indeed, I suspect so; I doubt that Knuth believes in the feasibility of such a "mathematization of categories" opened up by computers. Yet any imaginative reader would be likely to draw hints of such a notion out of Knuth's article, whether Knuth intended it that way or not. It is my purpose in this article to argue that such a vision is exceedingly unlikely to come about, and that such intriguingly flexible tools as meta-shoes, metafonts, modern electronic organs (with their "oom-pah-pah" and "cha-cha-cha" rhythms and their canned harmonic patterns), and other many-knobbed devices will only help us see more clearly why this is so. The essential reason for this I can state in a very short way: I feel that to fill out the full "space" defined by a category such as "chair" or "A" or "waltz" is an act of infinite creativity, and that no finite entity (inanimate mechanism or animate organism) will ever be capable of producing all possible "A" 's and nothing but "A" 's (the same could be said for chairs, waltzes, etc.).

I am not making the trivial claim that, because life is finite, nobody can make an infinite number of creations; I am making the nontrivial claim that nobody can possess the "secret recipe" from which all the (infinitely many) members of a category such as "A" can in theory be generated. In fact, my claim is that no such recipe exists. Another way of saying this is that even if you were granted an infinite lifetime in which to draw all the "A" 's you could think up, thus realizing the full potential of any recipe you had, no matter how great it might be, you would still miss vast portions of the space of "A" 's.

In metamathematical terms this amounts to positing that any conceptual (or "semantic") category is a "productive" set, a precise notion whose characterization is a formal counterpart to the description in the previous paragraphs (namely, a set whose elements cannot be totally enumerated by any effective procedure without overstepping the bounds of that set, but which can be approximated more and more fully by a sequence of increasingly complex effective procedures). The existence and properties of such sets first became known as a result of Gödel's Incompleteness Theorem of 1931 [Gödel 31]. It is certainly not my purpose here to explain this famous result, but a short synopsis might be of help. (Other useful references are: [Chaitin 75], [DeLong 70], [Hofstadter 79], [Nagel 58], [Rucker 82], [Smullyan 61], [Smullyan 78].)

An Intuitive Picture of Gödel's Theorem

Gödel was investigating the properties of purely formal deductive systems in the sphere of mathematics, and he discovered that such systems--even if their ostensible domain of discourse was limited to one topic--could be viewed as talking "in code" about themselves. Thus a deductive system could express, in its own formal language, statements about its own capabilities and weaknesses. In particular, System X could say of itself through the Gödelian code, "System X is not powerful enough to demonstrate the truth of Sentence S." It sounds a little bit like a science-fiction robot called "Robot 15" droning in a telegraphic monotone, "Robot-15 unfortunately unable to complete Task T-12--very sorry." Now what happens if Task T-12 happens, by some crazy coincidence, to be not the assembly of some strange cosmic device but merely the act of uttering the preceding telegraphic monotone? (I say "merely" but of course that is a bit ironic.) Then Robot-15 could get only partway through the sentence before choking: "Robot-15 unfortunately unable to comp--."

Now in the case of a formal system, System X, talking about its powers, suppose that Sentence G, by an equally crazy coincidence, is the one that says, "System X is regrettably not powerful enough to demonstrate the truth of Sentence G." In such a case, Sentence G is seen to be an assertion of its own unprovability within System X. In fact we do not have to rely on crazy coincidences, for Gödel showed that given any reasonable formal system, a G-type sentence for that system actually exists. (The only exaggeration in my English-language version of G is that in formal systems there is no way to say "regrettably.") In formal deductive systems this foldback takes place of necessity by means of a Gödelian code, but in English no Gödelian code is needed and the peculiar quality of such a loop is immediately visible.

If you think carefully about Sentence G, you will discover some amazing things. Could Sentence G be provable in System X? If it were, then System X would contain a proof for Sentence G, which asserts that System X contains no proof for Sentence G. Only if System X is blatantly self-contradictory could this happen--and a formal reasoning system that is self-contradictory is no more useful than a submarine with screen doors. So, provided we are dealing with a consistent formal system (one with no self-contradictions), then Sentence G is not provable inside System X. And since this is precisely the claim of Sentence G itself, we conclude that Sentence G is true--true but unprovable inside System X.

One last way to understand this curious state of affairs is afforded the reader by this small puzzle. Choose the more accurate of the following pair of sentences:

(1) Sentence G is true *despite* being unprovable.

(2) Sentence G is true *because* it is unprovable.

You'll know you've really caught on to Gödel when both versions ring equally true to your ears, when you flip back and forth between them, savoring that exceedingly close approach to paradox that G affords. That's how twisted back on itself Sentence G is!

The main consequence of G's existence within each System X is that there are truths unattainable within System X, no matter how powerful and flexible System X is, as long as System X is not self-contradictory. Thus, if we look at truths as objects of desire, no formal system can have them all; in fact, given any formal system we can produce on demand a truth that it cannot have, and flaunt that truth in front of it with taunting cries of "Nah, nah!" The set of truths has this peculiar and infuriating quality of being uncapturable by any finite system, and worse, given any candidate system, we can use what we know about that system to come up with a specific Gödelian truth that eludes provability inside that system.

By adding that truth to the given system, we come up with an enlarged and slightly more powerful system--yet this system will be no less vulnerable to the Gödelian devilry than its predecessor was. Imagine a dike that springs a new leak each time the proverbial Dutch boy plugs up a hole with his finger. Even if he had an infinite number of fingers, that leaky dike would find a spot he hadn't covered. A system that contains at least one unprovable truth is said to be "incomplete," and a system that not only contains such truths but that cannot be rescued in any way from the fate of incompleteness is said to be "essentially incomplete." Another name for sets with this wonderfully perverse property is "productive" [Rogers 67].

My claim--that semantic categories are productive sets--is, to be sure, not a mathematically provable fact but a metaphor. This metaphor has been used by others before me--notably, the logicians Emil Post and John Myhill--and I have written of it myself before (see [Post 44], [Myhill 52], [Hofstadter 79], and [Hofstadter 82a]).

Completeness and Consistency

Note that it is important to have the potential to fill out the full (infinite) space, and equally important not to overstep it. However, merely having infinite potential is not by any means equivalent to filling out the full space. After all, any existing Metafont "A"-schema--even one having just one degree of freedom!--will obviously give us infinitely many distinct "A" 's as we sweep its knob (or knobs) from one end of the spectrum to the other. Thus to have an "A"-making machine with infinite variety of potential output is not in itself difficult; the trick is to achieve *completeness:* to fill the space.

And yet, isn't it easy to fill the space? Can't one easily make a program that will produce all possible "A" 's? After all, any "A" can be represented as a pattern of pixels (dots that are either off or on) in an m x n matrix--hence a program that merely prints out all possible combinations of pixels in matrices of all sizes (starting with 1x1 and moving upwards to 2x1, 1x2, 3x1, 2x2, 1x3, etc., as in Georg Cantor's famous enumeration of the rational numbers) will certainly cover any given "A" eventually. This is quite true. So what's the catch?

Well, unfortunately, it is hard--very hard--to write a screening program that will retain all the "A" 's in the output of this pixel-pattern program, and at the same time will reject all "K" 's, pictures of frogs, octopi, grandmothers, and precognitive photographs of traffic accidents in the twenty-fifth century (to mention just a few of the potential outputs of the generation program). The requirement that one must stay within the bounds of a conceptual category could be called *consistency*--a constraint complementary to that of completeness.

In summary, what might seem desirable from a knobbed category-machine is the joint attainment of two properties--namely, (1) completeness: that all true members of a category (such as the category of "A" 's [Figure 1] or the category of human faces [Figure 2] should be potentially producible eventually as output; and (2) consistency: that no false members of the category ("impostors") should ever be potentially producible. In short, that the set of outputs of the machine should coincide exactly with the set of members of the intuitive category.

The twin requirements of consistency and completeness are metaphorical equivalents of well-known notions by the same names in metamathematics, denoting desirable properties of formal systems (theorem-producing machines) --namely, (1) completeness: that all true statements of a theory (such as the theory of numbers or the theory of sets) should be potentially producible eventually as theorems; and (2) consistency: that no false statements of the theory should ever be potentially producible. In short, that the set of theorems of the formal system should coincide exactly with the set of truths of the informal theory.

The import of Gödel's Incompleteness Theorem is that these two idealized goals are unreachable simultaneously for any "interesting" theory (where "interesting" really means "sufficiently complex"); nonetheless, one can

Figure 1. The category of "A"'s (drawn from [Letraset 81]).

Figure 2. The category of human faces (drawn from [Strich 81]).

approach the set of truths by stages, using increasingly powerful formal systems to make increasingly accurate approximations. The goal of total and pure truth is, however, as unreachable by formal methods as is the speed of light by any material object. I suggest that a parallel statement holds for any "interesting" category (where again, "interesting" means something like "sufficiently complex," although it is a little harder to pin down): namely, one can do no better than approach the set of its members by stages, using increasingly powerful knobbed machines to make increasingly accurate approximations.

Intuition at first suggests that there is a crucial difference between the (metamathematical) result about the nonformalizability of truth and the (metaphorical) claim about the nonmechanizability of semantic categories; this difference would be that the set of all truths in a mathematical domain such as set theory or number theory is objective and eternal, whereas the set of all "A" 's is subjective and ephemeral. However, on closer examination, this distinction begins to blur quite a bit. The very fact of Gödel's proven nonformalizability of mathematical truth casts serious doubt on the objective nature of such truth. Just as one can find all sorts of borderline examples of "A"-ness, examples that make one sense the hopelessness of trying to draw the concept's exact boundaries, so one can find all sorts of borderline mathematical statements that are formally undecidable in standard systems and which, even to a keen mathematical intuition, hover between truth and falsity. And it is a well-known fact that different mathematicians hold different opinions about the truth or falsity of various famous formally undecidable propositions (the axiom of choice in set theory is a classic example). Thus, somewhat counterintuitively, it turns out that mathematical truth has no fixed and eternal boundaries, either. And this suggests that perhaps my metaphor is not so much off the mark.

A Misleading Claim for Metafont

Whatever the validity and usefulness of this metaphor, I shall now try to show some evidence for the viewpoint that leads to it, using Metafont as a prime example of a "knobbed category machine." In his article, Knuth comes perilously close, in one throwaway sentence, to suggesting that he sees Metafont as providing us with a mathematization of categories. I doubt he suspected that anyone would focus in on that sentence as if it were the key sentence of the article--but as he did write it, it's fair game! That sentence ran:

> The ability to manipulate lots of parameters may be interesting and fun, but does anybody really need a 6 1/7-point font that is one fourth of the way between Baskerville and Helvetica?

This rhetorical question is fraught with unspoken implications. It suggests that Metafont as it now stands (or in some soon-available or slightly modified version) is ready to carry out, on demand, for any user, such an interpolation between two given typefaces. There is something very tricky about this proposition that I suspect most readers will not notice: it is the idea that jointly parametrizing two typefaces is no harder, no different in principle, from just parametrizing one typeface in isolation.

Indeed, to many readers, it would appear that Knuth has actually carried out such a joint parametrization. After all, in printing Psalm 23 [Figure 3] didn't he move from an old-fashioned, compact, serifed face with

Figure 3. Donald Knuth's virtuoso Metafont rendition of Psalm 23, in which the font for each character is determined by the settings of 28 knobs, all of which change slowly but steadily as the psalm progresses.

The LORD is my shepherd;
I shall not want.
He maketh me to lie down
in green pastures:
he leadeth me
beside the still waters.
He restoreth my soul:
he leadeth me
in the paths of righteousness
for his name's sake.
Yea, though I walk through the valley
of the shadow of death,
I will fear no evil:
for thou art with me;
thy rod and thy staff
they comfort me.
Thou preparest a table before me
in the presence of mine enemies:
thou anointest my head with oil,
my cup runneth over.
Surely goodness and mercy
shall follow me
all the days of my life:
and I will dwell
in the house of the LORD
for ever.

relatively tall ascenders and descenders and small x-height all the way to the other end of the spectrum: a modern-looking, extended, sans-serif face with relatively short ascenders and descenders and large x-height? Yes, of course--but the critical omitted point here is that these two ends of the spectrum were not pre-existing, prespecified targets; they just happened to emerge as the extreme products of a knobbed machine designed so that one more or less intermediate setting of its knobs would yield a particular target typeface (Monotype Modern Extended 8A).

In other words, this particular set of knobs was inspired solely and directly by an attempt to parametrize one typeface (Monotype Modern). The two extremes shown in the psalm are both variations on that single theme; the same can be said of every intermediate stage as well. There is only one underlying theme (Monotype Modern) here, and a cluster of several hundred variants of it, each one of which is represented by a single character. The psalm does not represent the marriage of two unrelated families, but simply exhibits many members of one large family.

Joint Parametrization of Two Typefaces: A Far Cry from Parametrizing One Typeface

You can envision all the variants of Monotype Modern produced by twiddling the knobs on this particular machine as constituting an "electron cloud" surrounding a single "nucleus" [Figure 4a]. Now by contrast, joint parametrization of two pre-existent, known typefaces (say, Baskerville and Helvetica, as Knuth suggests [Figure 5] would be like a cloud of electrons swarming around two nuclei, like a chemical bond [Figure 4b].

In order to jointly parametrize two typefaces in Metafont, you would need to find, for each pair of corresponding letters (say Baskerville "a" and Helvetica "a") a set of discrete geometric features (line segments, serifs, extremal points, points of curvature shift, etc.) that they share and that totally characterize them. Each such feature must be equated with one or more parameters (knobs), so that the two letterforms are seen as produced by specific settings of their shared set of knobs. Moreover, all intermediate settings must also yield valid instances of the letter "a". That is the very essence of the notion of a knobbed machine, and it is also the gist of the quote, of course: that we should now (or soon) be able to interpolate between any familiar typefaces merely by knob-twiddling.

Now I will admit that I think it is perhaps feasible--though much more difficult than parametrizing a single typeface--to jointly parametrize two typefaces that are not radically different. It is not trivial, to cite just one sample difficulty, to move between Baskerville's round dot over the "i" to Helvetica's square dot--but is is certainly not inconceivable. Conversely, it is not inconceivable to move between the elegant swash tail of the Basker-

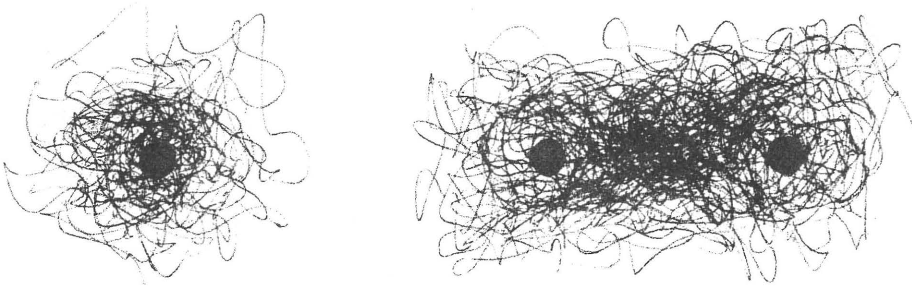

Figure 4. (a) An electron cloud surrounding a single nucleus; (b) A cloud of electrons around two nuclei, like a chemical bond.

abcdefghijklmnopqrstuvwxyz
ABCDEFGHIJKLMNOPQRSTUVWXYZ

abcdefghijklmnopqrstuvwxyz ß
ABCDEFGHIJKLMNOPQRSTUVWXYZ

Figure 5. Baskerville (above) and Helvetica.

i Q
i Q

Figure 6. Blow-ups of Baskerville and Helvetica "i" and "Q".

ville "Q" and the stubby straight tail of the Helvetica "Q"--but it is certainly not trivial [Figure 6].

Moving from letter to letter and comparing them will reveal that each of these two typefaces has features that the other totally lacks. (You should disregard lowercase "g", since the "g" 's of our two typefaces are as different from each other as Baskerville "B" is from Helvetica "H"; in both cases the two letterforms being compared derive from entirely different underlying "Platonic essences." (It is Metafont's purpose to mediate between different stylistic renditions of a single Platonic essence, not between distinct Platonic essences.) Presumably, in a case where one typeface possesses some distinct feature that the other totally lacks, there is a way to fiddle with the knobs that will make the feature nonexistent in one but present in the other. For instance, a knob setting of zero might make some feature totally vanish. Sometimes it will be harder to make features disappear--it might require several knobs to have coordinated settings. Nonetheless, despite all the complex ways that Baskerville and Helvetica differ, I repeat, it is conceivable that somebody with great patience and ingenuity could jointly parametrize Helvetica and Baskerville. But the real question is this: Would such a joint parametrization easily emerge out of two separate, independently carried-out parametrizations of these typefaces? Hardly!

The Baskerville knobs do not contain even a hint of the Helvetica qualities--or the reverse. How can I convince you of this? Well, just imagine how great the genius of John Baskerville would have had to be for his design to have implicitly defined another typeface--and a typeface only discovered (or invented) two centuries later! To see this more concretely, imagine that someone who had never seen Helvetica naively created a Metafont rendition of Baskerville (that is, a metafont centered on Baskerville in the same sense as Knuth's sample metafont is centered on Monotype Modern). Now imagine that someone else who does know Helvetica comes along, twiddles the knobs of this Baskerville metafont, and actually produces a perfect Helvetica! It would be nearly as strange as having a marvelous music-composing program based exclusively on the style of G. F. Handel (who composed in England in a baroque, elegant 18th-century style) that was later discovered, totally unexpectedly, to produce many pieces indistinguishable in style from the music of Ernest Bloch (who composed in Switzerland in a sparse, crisp 20th-century style) when various melodic, harmonic, and rhythmic parameters were twiddled. To me, this is simply inconceivable.

Interpolating between an Arbitrary Pair of Typefaces

The worst is yet to come, however. Presumably Knuth did not wish us to take his rhetorical question in such a limited way as to imply that the numbers 6 1/7 and 1/4 were important. Pretty obviously, they were just examples of arbitrary parameter settings. Presumably, if Metafont could easily give you a 6 1/7-point font that is 1/4 of the way between Baskerville and Helvetica, it could as easily give you an 11 2/3-point font that is 5/17 of the way between Baskerville and Helvetica--and so on. And why need it be restricted to Baskerville and Helvetica? Surely those numbers weren't the only "soft" parts of the rhetorical question! Common sense tells us that Helvetica and Baskerville were also merely arbitrary choices of typeface. Thus the hidden implication is that, as easily as one can twiddle a dial to change point size, so one can twiddle another dial (or set of dials) and arrive at any desired typeface, be it Helvetica, Baskerville, or whatever. Knuth might just as easily have put it this way: "The ability to manipulate lots of parameters may be interesting and fun, but does anybody really need an X-point font that is Y percent of the way between typeface T1 and typeface T2?" For instance, we might have set the four knobs to the following settings:

X: 36
Y: 50%
T1: Magnificat
T2: Stop

Each of these two typefaces [Figure 7a, b] is ingenious, idiosyncratic, and visually intriguing. I challenge any reader to even imagine a blend halfway between them, let alone draw it! And to emphasize the flexibility implied by the question, how about trying to imagine a typeface that is (say) one third of the way between Cirkulus and Block Up [Figure 7c, d]? Or one that is somewhere between Explosion and Shatter [Figure 7e, f]?

Figure 7. (a) Magnificat, (b) Stop, (c) Cirkulus, (d) Block Up, (e) Explosion, (f) Shatter, and (g) Helvetica Medium Italic.

''A Posteriori'' Knobs and the Frame Problem of AI

Shatter, incidentally, provides an excellent example of the trouble with viewing everything as coming from parameter settings. If you look carefully, you will see that Shatter is indeed a ''variation on a theme,'' the theme being Helvetica Medium Italic [Figure 7g]. But does that imply that any meticulous parametrization of Helvetica would automatically yield Shatter as one of its knob-settings? Of course not. That is absurd. No one in their right mind would anticipate such a variation while parametrizing Helvetica, just as no one in their right mind when delivering their Nobel Lecture would say, ''Thank you for awarding me my first Nobel Prize.'' When someone wins a Nobel Prize, they do not immediately begin counting how many they have won. Of course, if they win two, then a knob will spontaneously appear in most people's minds, and friends will very likely make jokes about the next few Nobel Prizes. Before the second prize, however, the ''just-one'' quality would have been an unperceived fact.

This is closely related to a famous problem in cognitive science (the study of formal models of mental processes, especially computer models) called the ''frame problem'' [Dennett 81], which can be epitomized this way: How do I know, when telling you I'll meet you at 7 at the train station, that it makes no sense to tack on the proviso, ''as long as no volcano erupts along the way, burying me and my car on the way to the station,'' but that it does make reasonable sense to tack on the proviso, ''as long as no traffic jam holds me up''? And, of course, there are many intermediate cases between these two. The frame problem is about the question, ''What variables (knobs) is it within the bounds of normalcy to perceive?'' Clearly, no one can conceivably anticipate all the factors that might somehow be relevant to a given situation; one simply blindly hopes that the species' evolution and the individual's life experiences have added up to a suitably rich combination to make for satisfactory behavior most of the time. There are too many contingencies, however, to try to anticipate them all, even given the most powerful computer. One reason for the extreme difficulty in trying to make machines able to learn is that we find it very hard to articulate a set of rules defining when it makes sense and when it makes no sense to perceive a knob.

This brings us back to Shatter, seen as a variation on Helvetica. Obviously, once you've seen such a variation, you can add a knob (or a few) to your Metafont ''Helvetica machine,'' enabling Shatter to come out. (Indeed, you could add similar ''Shatterizing'' knobs to your ''Baskerville machine,'' for that matter!) But this would all be a posteriori: after the fact. The most telling proof of the artificiality of such a scheme is, of course, that no matter how many variations have been made on (say) Helvetica, people can still come up with many new and unanticipated varieties, such as: Helvetica Rounded, Helvetica Rounded Deco, Helvetican Flair, and so on [Figure 8a, b, c] [Graphic 81].

Incidentally, it is important that I make it clear that although I find it easier to make my points with somewhat extreme or exotic versions of letters, these points hold just as strongly for more conservative letters. One simply has to look at a finer grain size, and all the same kinds of issues reappear.

No matter how many new knobs--or even new families of knobs--you add to your Helvetica machine, you will have left out some possibilities. People will forever be able to invent novel variations on Helvetica that haven't been foreseen by a finite parametrization, just as musicians will forever be able to devise novel ways of playing "Begin the Beguine" that the electronic-organ builders haven't yet built into their elaborate repertoire of canned rhythms, harmonies, and so forth. To be sure, the organ builders can always build in extra possibilities after they have been revealed, but by then a creative musician will have long since moved on to other styles. One can imagine Helvetica modified in many novel ways in-

Figure 8 (top to bottom). (a) Helvetica Rounded, (b) Helvetica Rounded Deco, and (c) Helvetican Flair [Graphic 81].

Figure 9 (top to bottom). (a) Sunrise, (b) Buster, (c) Stack, and (d) Double.

spired by various extant typefaces such as Sunrise, Buster, Stack, Double, and so on [Figure 9a, b, c, d]. I leave it to readers to try to imagine such variants.

A Total Unification of All Typefaces?

The worst is still yet to come! Knuth's throwaway sentence unspokenly implies that we should be able to interpolate any fraction of the way between any two arbitrary typefaces. For this to be possible, any pair of typefaces would have to share the exact same set of knobs (otherwise, how could you set each knob to an intermediate setting?). And since all *pairs* of typefaces have the same set of knobs, transitivity implies that *all* typefaces would have to share a single, grand, universal, all-inclusive, ultimate set of knobs. (The argument is parallel to the following one: If, given any two people, they have the same number of legs, then all people have the same number of legs.)

Thus we realize that Knuth's sentence casually implies the existence of a "universal 'A'-machine"--a single Metafont program with a finite set of parameters, such that any combination of settings of them will yield a valid "A", and conversely, such that any valid "A" will be yielded by some combination of settings of them. Now how can you possibly incorporate all of the previously shown typefaces into one universal schema?

Or look again at the 56 capital "A" 's of Figure 1. Can you find in them a set of specific, quantifiable features? (For a comparable collection for each letter of the alphabet, see [Kuwayama 73].) Imagine trying to pinpoint a few dozen discrete features of the Magnificat "A" (A7) and simultaneously finding their "counterparts" in the Univers "A" (D3). Suppose you have found enough to characterize both completely. Now remember that every intermediate setting also must yield an "A". This means we will have every shade of "cross" between the two typefaces.

This intuitive sense of a "cross" between two typefaces is common and natural, and occurs often to typeface lovers when they encounter an unfamiliar typeface. They may characterize the new face as a cross between two familiar typefaces ("Vivaldi is a cross between Magnificat and Palatino Italic Swash") or they may see it as an exaggerated rendition of a familiar typeface ("Magnificat is Vivaldi squared") [Figure 10]. What truth is there to such a statement? All one can really say is that each Magnificat letter looks "sort of like" its Vivaldi counterpart, only about "twice as fancy" or "twice as curly" or something vague along these lines. But how could a single "curliness" knob account for the mysteriously beautiful meanderings, organic and capricious, in each Magnificat letter?

Can you imagine twisting one knob and watching thin, slithery tentacles begin to grow out of the Palatino Italic "A", snaking outwards eventually to form the Vivaldi "A", then continuing to twist and undulate into ever more sinuous forms, yielding the Magnificat "A" in the end? And who says that that is the ultimate destination? If Magnificat is Vivaldi squared, then what is Magnificat squared?

Specialists in computer animation have had to deal with the problem of interpolation of different forms. For example, in a television series about evolution, there was a sequence showing the outline of one animal slowly transforming into another one. But one cannot simply tell the computer, "Interpolate between this shape and that one!" To each point in one there must be explicitly specified a corresponding point in the

Figure 10 (top to bottom). (a) Palatino Italic Swash caps, (b) Vivaldi caps, and (c) Magnificat caps.

other. Then one lets the computer draw some intermediate positions on one's screen, to see if the choice works. A lot of careful "tuning" of the correspondences between figures must be done before the interpolation looks good. There is no recipe that works in general.

The Essence of "A"-ness is Not Geometrical

Despite all the difficulties described above, some people, even after scrutinizing the wide diversity of realizations of the abstract "A"-concept, still maintain that they all do share a common geometric quality. They sometimes verbalize it by saying that all "A"'s have "the same shape" or are "produced from one template." Some mathematicians are inclined to search for a topological or group-theoretical invariant. A typical suggestion might be: "All instances of 'A' are open at the bottom and closed at the top." Well, in Figure 1, sample A8 (Stop) seems to violate both of those criteria. And many others of the sample letters violate at least one of them. In several examples, such concepts as "open" or "closed" or "top" or "bottom" apply only with difficulty. For instance, is G7 (Sinaloa) open at the bottom? Is F6 (Calypso) closed at the top? What about A4 (Astra)?

The problem with the Metafont "knobs" approach to the "A" category is that each knob stands for the presence or absence (or size or angle, etc.) of some specifically *geometric* feature of a letter: the width of its serifs, the height of its crossbar, the lowest point on its left arm, the highest point along some extravagant curlicue, the amount of broadening of a pen, the average slope of the ascenders, and so forth and so on. But in many "A" 's such notions are not even applicable. There may be no crossbar, or there may be two or three or more. There may be no curlicue, or there may be a few curlicues.

Chauvinism versus Open-Mindedness: Fixed Questionnaires versus Fluid Roles

A Metafont joint parametrization of two "A" 's presumes that they share the same features, or what might be called "loci of variability." It is a bold (and, I maintain, absurd) assumption that one could get any "A" by filling out an eternal and fixed questionnaire: "How wide is its crossbar? What angle do the two arms make with the vertical? How wide are its serifs?" (and so forth). There may be no identifiable part that plays the crossbar role, or the left-arm role; or some role may be split among two or more parts. You can easily find examples of these phenomena among the 56 "A" 's in Figure 1. Some other examples of what I call role splitting, role sharing, role transferral, role redundancy, and role elimination are shown in Figure 11. These terms describe the ways that conceptual roles

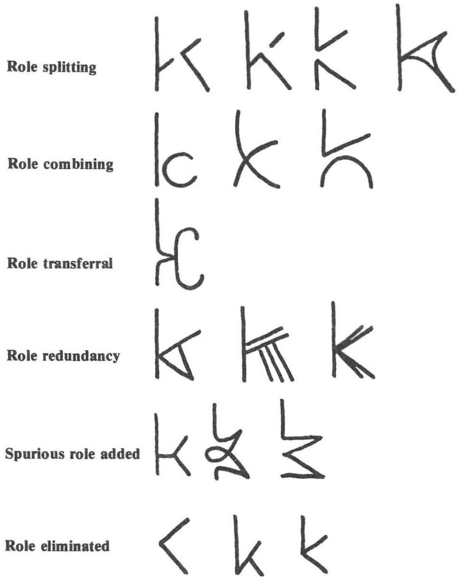

Figure 11.

are apportioned among various geometric entities, which are readily recognized by their connectedness and gentle curratures.

When I was 12, my family was about to leave for Geneva, Switzerland, for a year, so I tried to anticipate what my school would be like. The furthest my imagination could stretch was to envision a school that looked exactly like my one-story Californian stucco junior high school, only with classes in French (twiddling the "language" knob), and with the schoolbus that would pick me up each morning perhaps pink instead of yellow (twiddling the "schoolbus color" knob). I was utterly incaable of anticipating the vast difference that there actually turned out to be between the Geneva school and my California school.

Likewise, there are many "exobiologists" who have tried to anticipate the features of extraterrestrial life, if it is ever detected. Many of them have made assumptions that to others appear strikingly naive. Such assumptions have been dubbed "chauvinisms" by Carl Sagan [Sagan 73]. There is, for instance, "liquid chauvinism," which refers to the phase of the medium in which the chemistry of life is presumed to take place. There is "temperature chauvinism," which assumes that life is restricted to a temperature range not too different from that here on the planet earth. In fact, there is planetary chauvinism--the idea that all life must exist on the surface of a planet orbiting a certain type of star. There is carbon chauvinism, assuming that carbon must form the keystone of the chemistry of any sort of life. There is speed chauvinism, assuming that there is only one "reasonable" rate for life to proceed at. And so it goes.

If a Londoner arrived in New York, we might find it naive (or perhaps pathetic) if he or she asked "Where is your Big Ben? Where are your Houses of Parliament? Where does your Queen live? When is your teatime?" The idea that the biggest city in the land need not be the capital, need not have a famous bell tower in it, and so on, seem totally obvious after the fact, but to the naive tourist it can come as a surpise.

The point here is that when it comes to fluid semantic categories such as "A", it is equally naive to presume that it makes sense to refer to "the crossbar" or "the top" or to any constant feature. It is quite like expecting to find "the same spot" in any two pieces of music by the same composer. The problem, I have found, is that most people continue to insist that any two instances of "A" have "the same shape," even when confronted with such pictures as Figure 1.

The analogy between Britain and the United States is a useful one to continue for a moment. The role that London plays in England is certainly multifaceted, but two of its main roles are "chief commercial city" and "capital." These two roles are played by different cities in the U.S. On the other hand, the role that the American President plays in the U.S. is split into pieces in Britain, part being carried by the Queen (or King), and part by the Prime Minister. Then there is a subsidiary role played by the President's wife--the "First Lady." Her counterpart in Britain is also split, and moreover, these days "wife" has to be replaced by "husband," whether one is thinking that the "President of England" is the Queen or the Prime Minister. (See [Hofstadter 81] for an extended discussion of such analogy problems and their relation to machine intelligence.)

To think one can anticipate the complete structure of one country or language purely on the basis of being intimately familiar with another one is presumptuous and, in the end, preposterous. Even if you have seen dozens, you have not exhausted the potential richness and novelty in such domains. In fact, the more instances you have seen, the more circumspect you are about making unwarranted presumptions about unseen instances, although certainly your ability to anticipate the unanticipated (or unanticipable) improves! The same holds for instances of any letter of the alphabet or other semantic category.

The "A" Spirit

Clearly there is much more going on in typefaces than meets the eye--literally. The shape of a letterform is a surface manifestation of deep mental abstractions. It is determined by conceptual considerations and balances that no finite set of merely geometric knobs could capture. Underneath or behind each instance of "A" there lurks a concept, a Platonic entity, a *spirit.* This Platonic entity is not an elegant shape such as the Univers "A", not a template with a finite number of knobs, not a topological or group-theoretical invariant in some mathematical heaven, but a mental abstraction--a different sort of beast. Each instance of the "A" spirit reveals something new about the spirit without ever exhausting it. The mathematization of such a spirit would be a machine with a specific set of knobs on it, defining all its "loci of variability" for once and for all. I have tried to show that to expect this is simply not reasonable. In fact, I made the following claim, above: "No matter how many new knobs--or even new families of knobs--you add to your . . . machine, you will have left out some possibilities. People will forever be able to invent novel variations . . . that haven't been foreseen by a finite parametrization. . . ."

Of what, then, is such an abstract "spirit" composed? Or is it simply a mystically elusive, noncapturable essence that defies the computational--indeed, the scientific--approach totally? Not at all, in my opinion. I simply think that a key idea is missing in what I have described so far. And what is this key idea? I shall first describe the key misconception. It is to try to capture the essence of each separate concept in a separate "knobbed machine"--that is, to isolate the various Platonic spirits. The key insight is that those spirits overlap and mingle in a subtle way.

Happy Roles, Unhappy Roles, and Quirk-Notes

The way I see it, the Platonic essence lurking behind any concrete letterform is composed of conceptual "roles" rather than geometric parts. (A related though not identical notion called "functional attributes" was discussed by Barry Blesser and co-workers nearly ten years ago in *Visible Language* [Blesser 73].) A role, in my sense of the term, does not have a fixed set of parameters defining the extent of its variability, but it has instead a set of tests or criteria to be applied to candidates that might be instances of it. For a candidate to be accepted as an instance of the role, not all the tests have to be passed; not all the criteria have to be present. Instead, the candidate receives a score computed from the tests and criteria, and there is a threshold point above which the role is "happy," and below which it is "unhappy." Then below that, there is a cut-off point below which the role is totally dissatisfied, and rejects the candidate outright.

An example of such a role is that of "crossbar." Note that I am not saying "crossbar in capital 'A', but merely "crossbar." Roles are modular: they jump across letter boundaries. The same role can exist in many different letters. This is, of course, reminiscent of the fact that in Metafont a serif (or generally, any geometric feature shared by several letters) can be covered by a single set of parameters for all letters, so that all the letters of the typeface will alter consistently as a single knob is turned. The difference is that my notion of "role" doesn't have the generative power that a set of specific knobs does. From the fact that a given role is "happy" with a specific geometric filler, one cannot deduce exactly how that filler looks. There is, of course, more to a role's "feelings" about its filler than simply happiness or unhappiness; there are a number of expectations about how the role should be filled, and the fulfillment (or lack thereof) can be described in "quirk-notes." Thus, quirk-notes can describe the unusual slant of a crossbar [Figure 1, E1 (Arnold Böcklin)], the fact that it is filled by two strokes rather than one [Figure 1, E3 (Airkraft)], or the fact that it fails to meet (or has an unusual way of meeting) its vertical mate [Figure 1, A2 (Eckmann Schrift), F5 (Le Golf), and many others].

These quirk-notes are characterizations of stylistic traits of a perceived letterform. They do not contain enough information, however, to allow a full reconstruction of that letterform, whereas a Metafont program does contain enough information for that. However, they do contain enough information to guide the creation of many specific letterforms that have the given stylistic traits. All of them would be, in some sense, "in the same style."

Modularity of Roles

The important thing is that this modularity of roles allows them to be exported to other letters, so that a quirk-note attached to a particular role in "A" could have relevance to "E", "L", or "T". Thus stylistic consistency among different letters is a by-product of the modularity of roles, just as the notion of letter-spanning parameters in Metafont gives rise to internal consistency of any typeface it might generate.

Furthermore, there are connections among roles so that, for instance, the way in which the "crossbar" role is filled in one letter could influence the way that the "post" or "bowl" or "tail" role is filled in other letters. This is to avoid the problem of overly simplistic mappings of one letter onto another, analogous to the Londoner asking an American where the American Houses of Parliament are. Just as one must interpret "Houses of Parliament" liberally rather than literally when "translating" from England to the U.S., so one may have to convert "crossbar" into some other role when looking for something analogous in the structure of another letter than "A", such as "N". In certain typefaces the diagonal stroke in "N" could well be the counterpart of the crossbar in "A". But is is important to emphasize that no fixed (i.e., typeface-independent) mapping of roles in "A" onto roles in "N" will work; only the specific letterforms themselves (via their quirk-notes) can determine what roles (if any) should be mapped onto each other. Such cross-letter mappings must be mediated by a considerable degree of understanding of what functions are fulfilled by all the roles in the two particular letters concerned. (This fluid mapping of roles is discussed in more detail in [Hofstadter 82b].)

Typographical Niches and Rival Categories

So far I have sketched very quickly a theory of "Platonic essences" or "letter spirits" involving modular roles--roles shared among several letters. This sharing of roles is one aspect of the overlapping and mingling that I spoke of above. There is a second aspect, which is suggested by the phrase "typographical niche." The notion is analogous to that of "ecological niche." When, in the course of perception of a letterform, a group of roles have been activated and have decided that they are present (whether happily or unhappily), their joint presence constitutes evidence that one of a set of possible letters is present. (Remember that since a role is not the property of any specific letter, its presence does not signal that any specific letter is in view.)

For instance, the presence of a "post" role and a "bowl" role in certain relative positions would suggest very strongly that there is a "b" present. Sometimes there may be evidence for more than one letter. The eye-mind combination is not happy with any such unstable state for long, and strains to make a decision. It is as if there is a very steep and slippery ridge between valleys, and a ball dropped from above is very unlikely to come to settle on top of the ridge. It will tumble to one side or the other. The valleys are the typographical niches.

Now the overlapping of letters comes about because each letter is aware of its typographical rivals, its next-door neighbors, just over the various ridges that surround its space. The letter "h", for instance, is acutely sensitive to the fact that it has a close rival in "k", and vice versa [Figure 12]. The letter "T" is very touchy about having its crossbar penetrated by the post below, since even the slightest penetration is enough to destroy its "T"-ness and to slip it over into "T"'s arch-rival niche, "t". It's a low ridge, and for that reason, "T" guards it extra-carefully.

The Intermingling of Platonic Essences

This image is, I hope, sufficiently strong to convey the second sense of overlapping and intermingling of Platonic essences. "No letter is an island," one might say. There has to be much mutual knowledge spread about among all the letters. Letters mutually define each others' essences, and this is why an isolated structure supposedly representing a single letter in all its glory is doomed to failure.

A letterform-designing computer program based on the above-sketched notions of typographical roles and niches would look very different from one that tried to be a full "mathematization of categories." It would involve an integration of perception with generation, and moreover an ability to generalize from a few letterforms (possibly as few as one) to an entire typeface in the style of the first few. It would not do so infallibly; but of course it is not reasonable to expect "infallible" performance, since stylistic consistency is not an objectively specifiable quality.

In other words, a computer program to design typefaces (or anything else with an esthetic or subjective dimension) is not an impossibility; but one should realize that, no less than a human, any such program will necessarily have a "personal" taste--and it will almost certainly not be the same as its designers' taste. In fact, to the contrary, the program's taste will quite likely be full of unanticipated surprises to its programmers (as well as to everyone else), since that taste will emerge as an implicit and remote consequence of the interaction of a myriad features and factors in the architecture of the program. Taste itself is not directly programmable. Thus, although any esthetically programmed computer will be "merely doing what it was programmed to do," its behavior will nonetheless often appear idiosyncratic and even inscrutable to its programmers, reflecting the fact--well known to programmers--that often one has no clear idea (and sometimes no idea at all) just what it is that one has programmed the machine to do!

Figure 12. Versions of "h" and "k" as rivals for the same typographical niche.

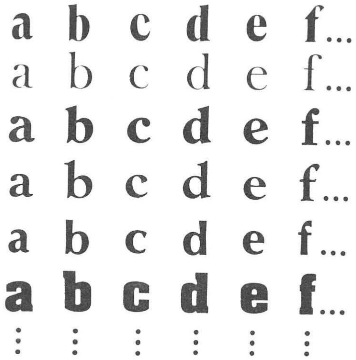

Figure 13. The vertical and horizontal problems.

The "Vertical" and "Horizontal" Problems:
Two Equally Important Facets of One Problem

I have made a broad kind of claim: that true understanding of letterforms depends on more than understanding something about each Platonic letter in isolation; it depends equally much on taking into account the ways that letters and their pieces are interrelated, on the ways that letters depend on each other to define a total style. In other words, any approach to the impossible dream of the "secret recipe" for "A-ness" requires a simultaneous solution to two problems, which I call the "vertical" and the "horizontal" problems [Figure 13]. The former is the question, "What do all the items in any column have in common?" The latter is the question, "What do all the items in any row have in common?"

Actually, there is no reason to stop with two dimensions; the problem seems to exist at higher degrees of abstraction. We could lay out our table of comparative typefaces more carefully; in particular, we could make it consist of many layers stacked on top of each other, as in a cake. On each layer would be aligned many typefaces made by a single designer. This idea is illustrated in Figure 14, showing a few faces designed by Hermann Zapf (Optima, Palatino, Melior, Zapf Book, Zapf International, Zapf Chancery) (see [Zapf 60]). Along with the Zapf layer, one can imagine a Frutiger layer, a Lubalin layer, a Goudy layer, and so on. One could try to arrange the typefaces in such a way that "corresponding" typefaces by various designers are aligned.

Now in this three-dimensional cake, the two earlier one-dimensional questions still apply, but there is also a new two-dimensional question: "What do all the items in a given layer have in common?" The third dimension can be explored as one moves from one layer to another, asking what all the typefaces in a given "shaft" have in common.

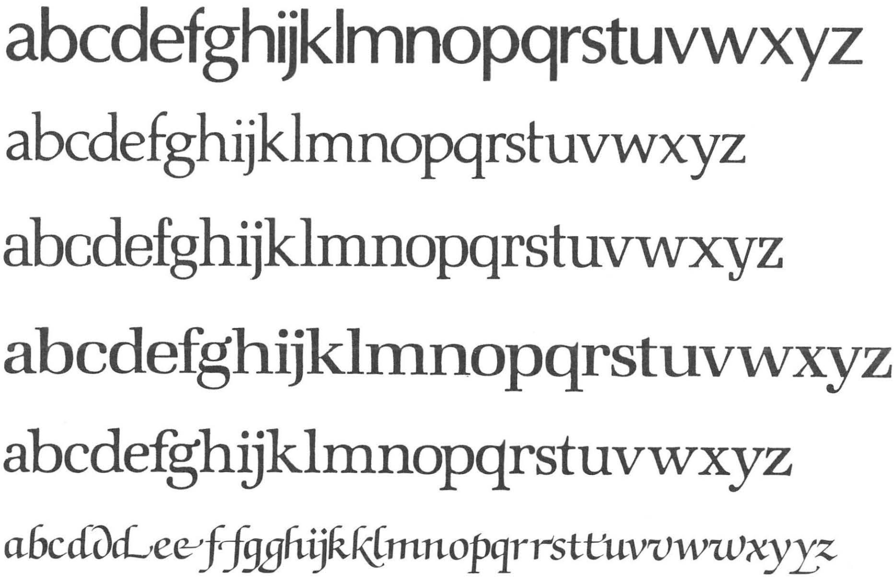

Figure 14. A few faces designed by Hermann Zapf (top to bottom). (a) Optima, (b) Palatino, (c) Melior, (d) Zapf Book, (e) Zapf International, and (f) Zapf Chancery.

Moreover, a fourth dimension can be added if you imagine many such "layercakes," one for each distinguishable period of typographical design. Thus our fourth dimension, like Einstein's, corresponds to time. Now one can ask about each layercake, "What do all the items herein have in common?" This is a three-dimensional question. Presumably, one could carry this exercise even further.

If we go back to the "simplest" of these questions, the original "vertical" question of Figure 13, a naive answer to it could be stated in one word: "Letter." And likewise, a naive answer to the "horizontal" question of Figure 13 is also statable in one word: "Spirit." In fact, the word "spirit" is applicable, in various senses of the term, to all the higher-dimensional questions, such as "What do all the typefaces produced in the Art Deco era have in common?" There is such a thing, ephemeral though it may be, as "Art Deco spirit," just as there is undeniably such a thing as "French spirit" in music or "impressionistic spirit" in art (see [Loeb 75]).

Stylistic moods permeate whole periods and cultures and indirectly determine the kinds of creations that people in them come up with. They exert gentle but definite "downward" pressures. As a consequence, not only are the alphabets of a given period and area distinctive, but one can even recognize "the same spirit" in such things as teapots, coffee cups, furniture, automobiles, architecture, and so on [Bush 75]. And one can also be inspired by a given typeface to carry its ephemeral spirit over into another alphabet, such as Greek, Hebrew, Cyrillic, or Japanese. In fact, this has been done in many instances [Figure 15]. The problem I am most concerned with in my research is whether (or rather, how) susceptibility to such a "spirit" can be implanted in a computer program.

Letter and Spirit

These words "letter" and "spirit," of course, recall the contrast between the "letter of the law" and the "spirit of the law," and the way in which our legal system is constructed so that judges and juries will base their decisions on precedents. This means that any case must be "mapped," in a remarkably fluid way, by members of a jury, onto previous cases. It is up to the opposing lawyers, then, to be advocates of particular mappings; to try to channel the jury members' perceptions so that one mapping dominates over another. It is quite interesting that jury decisions are supposed to be unanimous, so that in a metaphorical sense, a "phase transition" or "crystallization" of opinion must take place. The decision must be solidly locked in, so that it reflects not simply a majority or even a consensus, but a totality, a unanimity (which, etymologically, means "one-souledness"). (For discussions of such "phase transitions," see [Hofstadter 82c] and [Hofstadter 83], and for descriptions of computer models of perception in which a form of collective decision making is carried out, see [Reddy 76] and [Winston 75].)

In law, extant rules, statutes, and so on are never enough to cover all possible cases (reminding us once again of the fact that no fixed and rigid set of "A"-defining rules can anticipate all "A" 's). The legal system depends on the notion that people, whose experience covers much more than the specific case and rules at hand, will bring to bear their full range of experience not only with many categories but also with the whole process of categorization and mapping. This allows them to transcend the specific, rigid, limited *rules,* and to operate according to more fluid, imprecise, yet more powerful *principles.* Or, to revert to the other vocabulary, this ability is what allows people to transcend the letter of the law and to apply its spirit. It is this tension between rules and principles, between the letter and the spirit, that is so admirably epitomized for us by the work of Knuth and others exploring the relationship between artistic design and mechanizability. We are entering a very exciting and important phase of our attempts to realize the full potential of computers, and Knuth's article points to many of the significant issues that must be thought through very carefully.

Figure 15. The "spirit" of some Roman typefaces carried over into Cyrillic and Greek typefaces [Compugraphic 82] and into Hebrew and Japanese typefaces [Biggs 77]. The related Kana and Latin letters were designed by Yasaburo Kuwayama for the Nissan Company.

TASTE IN PRINTING DETERMINES THE FORM TY pography is to take. The selection of a congruous typeface the quality and the suitability for its purpose of the paper

English Times Bold

ШРИФТОТЕКА КОМПЬЮГРАФИК СОДЕРЖИТ дысяза гарнитуров шрифта включаюющихкак традич ио нные так современные рисунк шрифта, кото рые

Cyrillic Times Bold

TASTE IN PRINTING DETEkMINES THE FORM TYPOGR aphy is to take. The selection of a congruous typeface, the quality and suitability for its purpose of the paper being us

Oracle Italic

'Η καλαισθησιά καί ἡ ἀπόδοση στήν ἐκτύπωση προσ διο ρίξει μορφή πού θάρει τό τυπωμένο κείμενο τήν ἐπι λογή τοῦ ἀνάλογου ὀφθαλμοῦ, τήν ποιότητα καί

Greek

אות עברית זאת,הראשונה שעוצבה	**This type face,the first**
בארבעה משקלות,הותאמה במיוחד	**in Hebrew to be available**
לשימוש עם סדרת יוניברס הלטינית.	in four weights, is also
זאת הפעם הראשונה שאות עברית	the first designed specially
הותאמה לאותיות הקטנות באלף בית לטיני	to align with the lower case
כך שיתאימו במיוחד, זו בצד זו, לטקסטים	of a Latin type face, for use
דו לשוניים ארוכים, בהם השימוש באותיות	together in bilingual printing
הגדולות (caps) בלבד יפגע מאוד בקריאות.	of extended texts.

アイウエオカキク	ABCDEFGHI
ケコサシスセソタ	JKLMNOPQR
チツテトナニヌネ	STUVWXYZ&
ノハヒフヘホマミ	1234567890:,
ムメモヤユヨラリ	abcdefghijkl-
ルレロワヲンガグ	mnopqrstuvw
ゲザジズダヅバビ	xyz
パピプペー・ァィゥェ	

To conclude, then, I wish to state that the mathematization of categories is an elegant goal, a wonderful beckoning mirage before us, and the computer is the obvious medium to exploit to try to realize this goal. Donald Knuth, whether he has been pulled by a distant mirage or by an attainable middle-range goal, has contributed immensely, in his work on Metafont, to our ability to deal with letterforms flexibly, and has cast the whole probem of letters and fonts in a much clearer perspective than ever before. Readers, however, should not pull a false message out of his article: they should not confuse the chimera of the mathematization of categories with the quest after a more modest but still fascinating goal. In my opinion, one of the best things Metafont could do is to inspire readers to chase after what Knuth has rightly termed "the intelligence" of a letter, making use of the explicit medium of the computer to yield new insights into the elusive "spirits" that flit about so tantalizingly, hidden just behind those lovely shapes we call "letters."

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Other Replies to Donald E. Knuth's article, "The Concept of a Meta-Font"

To the Editor:

I am thankful for the opportunity to welcome a major contribution not only to the pages of this journal but also to the history of written interchange.

A few years ago I was staying with a couple of journalists in Washington. Knowing my interests they showed me a press release from Stanford University announcing Donald Knuth's Meta-Font. No mathematics were needed to understand that Knuth is a mathematician grown definitely exasperated with the shortcomings of composing techniques for mathematical proceedings. Mathematics, not Latin, being the universal language for scientists today, he determined to find a mathematical yet practical solution to the problems of technical composition in general.

It is important to note that before he set out to work he first consulted the appropriate historical sources as well as a number of distinguished contemporary type designers. In due time (1979) he published a series of articles in the Bulletin of the American Mathematical Society. The article in Visible Language is expressly intended to bring the ideas of a metafont home to a public of generalists, if not to the general public.

The result is not pleasant to look at. Nor is it intended to please the eye. It is not a poem; it is a prosody.

To the Editor:

The Greek word "meta-" is derived from the proto-Indo-European prefix *me-, meaning "in the middle of," related to English "mid-." It would therefore be appropriate if Donald Knuth found himself in the midst of a controversy over his "concept of a Meta-Font" (a situation which he would no doubt enjoy).

The fundamental idea of a metafont, independent of a modern cybernetic materialization of it, has been a common theme in the history of typography. In fact, if we wished to adopt a teleological bias, we could claim that a major force in typographic evolution has been the progressive exfoliation of the meta-ness of meta-fonts.

In this view, French typography in the second half of the sixteenth century can be seen as devoted to the expansion of Claude Garamond's quintessential roman typeforms throughout a complete range of body sizes, from the small nonpareil to the large canon. This triumph of design in the dimension of "scale" (size) — today a trivial problem — was an enormous undertaking for traditional punch-cutting technology. Many of the sizes were cut by Garamond himself, but many were also accomplished by the hands of other punch-cutters working in Garamond's idiom: Guillaume Le Bé, Robert Granjon, Pierre Haultin, Jacques Sabon.

Not to be read, but to be studied. It is a methodic demonstration of a meta-font and the interchangeable parameters on its design. Not at all intended to set any typographic standards while pointing out the "lamentable degradation" of quality in current practice.

Again, it is important to note that in his conclusion he turns to the type designers as "the professionals who really know the subject," hoping they will begin to create meta-fonts in their own explicit language. Let the type designers and the type manufacturers speak for themselves. What I would like to say as a teacher of letterforms is the following.

Knuth's attitude may well be as significant as the results of his research. It clearly indicates that to him letterforms and letterform design are major factors, not mere variables or interchangeable parameters in the cultural system of any literate civilization today.

It would seem to me that Knuth's attitude and the resulting Meta-Font is in keeping with the developing school of systemic thought (as represented in French by E. Morin and in English by Bronowski and Laszlo, to name a few). There may be some hope that a new philosophy of education will soon emerge along the same systemic lines to meet the challenge of the steadily oncoming technologies and the resulting waves on the ocean of human history. There is also some reason then to hope that writing, in the sense of written interchange, will at long last be considered for what it has always been, namely: one continuity of related and interconnected systems co-extensive with human history and constituting the very nervous

During the same period, the roman and italic forms, distinct entities in Aldine typography, were mated into a single family. The roman became the dominant text form, semiologically unmarked, and the italic became the subordinate form, semiologically marked, to signify difference, emphasis, contrast, etc. Thus, two originally rival forms became united in structural opposition as distinctive features of the text image. Robert Granjon established the dominant style of italic by cutting several sizes of his "pendante" form to mate with Garamond romans.

Toward the end of the sixteenth century, the Antwerp printer Christopher Plantin began the exploration of yet another dimension of meta-font: the relation of x-height to body size. Plantin commissioned re-cuttings of Garamond-style fonts to have shorter ascenders and descenders for use on a smaller body. Robert Granjon and Hendrik van den Keere both cut these large x-height variants for Plantin, in sizes including cicero, philosophie, and colineus by Granjon and canon and texte by Van den Keere.

In seventeenth-century Holland the amalgamation of roman and italic was furthered by the trend for a single punch-cutter to cut both roman and italic forms, precisely harmonized in body size, alignment, and color. The types of Christoffel van Dijk and Totfalusi Kis Miklos are examples.

In the mid- to late eighteenth century Pierre-Simon Fournier cut several variations of both roman and italic for each of the major body sizes. The dimensions of Fournier's meta-fonts included x-height, network of any future social life on this planet.

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To the Editor:

It was with great interest that I read Donald Knuth's article "The Concept of Meta-font." I had read his recent book, Tex and Meta-font, and was extremely impressed with the possibilities that this program offered to the typographic design field. In his article, Knuth demonstrates the power of his program by modifying the parameters so that his text is his example. Personally, I have often dreamed of the day when each student would have such a text to illustrate the particularities of the various structures and families of letters. With this program the text becomes a real typographic illustration! If we consider that images are stronger than words, Knuth has realized the juncture between text and image by using only typography. Perhaps a new expression like "imagintext" would be more appropriate.

Many typographic designers, myself included, never really believed that one day a computer program could be created that would be capable of rendering the subtlety of perception that is required for alphabet design I remember when in 1969 while working in Basel with André Gürtler on the IMB computer alphabet program one of the engineers was forever asking questions about choices I was making in adapting several existing alphabets and in particular the Univers series. He simply width, and weight, as well as roman and italic, and size. For the cicero body, Fournier cut ten variations, seven roman and three italic. Following Fournier, Giambattista Bodoni cut an even greater number of subtle variations of x-height, weight, width, and style for each major body size. In fact, Bodoni was so prolific in producing manifold variations that the profusion of his forms has constituted a puzzle for modern typefoundries seeking to revive the essential Bodoni. Which of the different types cut by Bodoni is really a "Bodoni"?

The nineteenth century also saw an explosion of experimental type forms from English foundries supplying display fonts for the arts of persuasion and promotion necessitated by the products of the industrial revolution. The sans-serif, egyptian, and clarendon joined the traditional roman in ad hoc metafonts in which the treatment of terminals became another dimension of variation. Moreover, the nineteenth century use of clarendon forms as bold companions for the roman and italic couple led to the tri-partite roman, italic, and semibold family which is now the standard for text typography.

In the early twentieth century, Morris Fuller Benton at ATF expanded several faces, including Cheltenham and Century, into extensive typeface families with several dimensions of variation, including weight, width, and style. Benton's creation of extended meta-families has been institutionalized in the recent creations produced by the International Typeface Corporation.

Adrian Frutiger's Univers family of 1957 shows a programmatic apcouldn't understand why there wasn't a more rational way to build letterforms. I told him that typographic designers have developed a feeling for these forms over many years of practice in the field of calligraphy, design of different letters, and the study of the historic development of forms. Knowledge of all these elements contribute to solving typographic problems. Even IBM and Alphanumeric — who at this time were using high technological processes to transfer original alphabets to a computer digital system — experienced certain problems they had not foreseen. It was with great satisfaction that I realized that the skills of a typographic designer were still an essential part of the final design quality.

I had a similar experience with the Canadian Communication Research Center when working on the Videotext system for Teledon. They were using a poor quality alphabet, and I was able to create four sans-serif roman alphabets as close to the traditional form as the technology allowed. I also had to adapt the new Cree syllabic writing system.

In 1980, when I recovered from the shock of reading Knuth's book and fully realized that here was a program that described mathematically the design of different variations of S (one of the most difficult letters to render), my enthusiasm knew no bounds. I shared this discovery with my students and found that this was not a very good way to present this work to beginners in the graphic design field. Their reaction was "Well, if a program can do it so well, what need is there for us to work so hard in your calligraphy and typography classes?"

plication of meta-font concepts to the traditional grotesque sans-serif. Frutiger's rigorous delineation of formal variations was in cultural agreement with the philosophy of "structuralism" then ascendant in French academic and intellectual circles. Later sans-serif families such as Karl Gerstner's and Christian Mengelt's Programme of 1963 have applied similar programmatic principles to typeface development.

In the 1930's Jan van Krimpen conceived of a super-family of designs, Romulus, which included a roman, a sloped roman, a chancery script, a wide bold, a narrow bold, four weights of sans-serif, and a Greek. Work on this meta-font was interrupted by the Nazi invasion of Holland, but Van Krimpen's ideas have since resurfaced in designs by his associates and countrymen.

For Monotype, John Dreyfus commissioned the Photina typeface by Jose Mendoza (1972) as a serified design family which could align and mate with Monotype Univers. Dutch designer Gerard Unger's Praxis family of sans-serifs mates with his Demos family of serified designs, released by Hell-Digiset 1977-79. Bram de Does, typographer at the Enschedé firm where van Krimpen worked, has designed the Trinité family with three variations in x-height as well as variations in width and weight, released by Autologic and Enschede in 1982.

Thus, Donald Knuth's Meta-Font is firmly within the typographic tradition. The meta-font is neither new nor original as a concept, but what is original about Knuth's meta-font is the explicit implementation of the design ideas in a computer system. Of course, the computer

I don't believe I gave them a satisfactory answer at the time!

Knuth's mathematical work on letters is the best I know in the field. As he himself said "I am not a designer and suggest that a talented designer working with appropriate mathematical tools will be able to produce something better than we now have." This mathematical tool will be a great asset to talented designers. However, I wonder what will we teach to beginners? How will they get the knowledge we got by practicing the design of letterforms? How will they learn to feel the forms? Can one develop a visual sensitivity by only looking at things on a screen! I really wonder . . . .

A lot of questions come to mind for which I have no solid answers. A basic visual sensitivity will still be part of any student's graphic education, but what part of the tradition should survive? We must be logical. Why teach students to design alphabets when fewer alphabets will be needed, and those that will be required can easily be produced by a few talented designers with Knuth's program? The graphic designer of the future will be someone who manipulates a computer instead of a pen and pencil.

Until such a time as every school of graphic design is equipped with advanced technology, I would greatly appreciate any advice that my colleagues who are presently teaching may have to offer. This exchange of ideas is essential to curriculum planning and student preparation.

In conclusion I would like to concur with C. Gordon Bell who, on the fly-leaf of Knuth's book, wrote "TEX . . . . introduces a standard language requires rational, logical, and algorithmic descriptions, whereas the history of typeface evolution has been replete with accident, idiosyncracy, serendipity, virtuosity, fortuity, and all of the other irrational, illogical, and intuitive forces to which art is subject.

The differences between the mathematical mind and the intuitive mind were characterized most lucidly by Pascal in his Pensées: "These things are so delicate and numerous that it takes a sense of great delicacy and precision to perceive them and judge correctly and accurately from this perception: most often it is not possible to set it out logically as in mathematics, because the necessary principles are not ready to hand, and it would be an endless task to undertake. The thing must be seen all at once, at a glance, and not as a result of progressive reasoning . . . ."

Charles Bigelow
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To the Editor:

Computer-aided design is here to stay in myriad fields. Standard industrial parts, the assembly line, electricity, the motor car, and advertising have swept into every corner of life casually invited. The computer is the current re-former of contemporary life.

Years ago people stayed close to home — travelling only as far as a horse could comfortably go when necessary. People left home to change jobs, attend weddings and funerals. Then the train, the horseless carriage, the motor car, the for computer typography and in terms of importance could rank near the introduction of Gutenberg press."

Henri-Paul Bronsard
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Canada

Thanks to Valery Mollar for English translation and corrections.

To the editor:

The typefaces used by Donald Knuth are ugly and seem amateurishly rendered — at least they seem that way to me. Your covering letter tells us that we shouldn't be concerned with appearance — that "it is the IDEA behind a meta-font that should concern us."

Well, I am excited about the IDEA, but so far I'm unconvinced about its relevance. I am a book designer and not a type designer. Maybe the type designers will be impressed — as I am — by the potential labor-saving aspects of this system. But so long as Knuth uses for his visual display typefaces that are ungainly, and indulges in the fun-and-games of modifying each of the 26 lines of Psalm 23 from serif to sans serif, we are stuck with potential abilities — as opposed to reality.

And how often this has happened in the past! A new computer program is advanced, and new typefaces issued, with everything from super-condensed to super-expanded variations. And the person who has to use these typefaces (like me) stares dully at the variations knowing he will never in a million years use all this magic stuff.

automobile, the airplane, the car changed all. Mobility for everyone allowed families to migrate, yet remain close; vegetables to reach the winter table; and youthful drunks to snuff out, undetected, the lives of strangers.

So it is with computers and type. Good and bad uses for typographic production are weeded out in the market place. But type design aided by computers rests entirely with the background and experience of the designer. Conception unconfined ascends only to the level of the creative abilities of the designer. Unfortunately, he who has acquired a computer is much like a youth who "gets wheels." Having access does not produce experience. Would a calligrapher contemplate the building of a calculator if he wearied of keeping his checkbook balance? Perhaps. Would he attempt its invention without consulting a mathematician or an electrical engineer? Unlikely. Yet the alphabet is such "common" stuff that half of the signs in America have backward roman As, Ms, Ws, Ys, without a trace of embarrassment. And now, precocious letter designers nudge their pixilated forms for posterity. The only problem with CAD for type is the lack of calligraphic and lettering background in the computer-side users. The computer in the hands of a letterer is one thing, but a computer expert without years of calligraphic background can easily think that his letters are acceptable when in fact they bear slight resemblance to real letters — the subtle conveyors of civilization.

Plimpton on triangle for one night with the New York Philharmonic is one thing, but computer on A-Z is

So what is needed are more convincing letterforms and solutions to the difficulties surrounding the creation of type fonts. Knuth seems to be aware of what the bread-and-butter concerns of type founding should be. For instance, he talks about the problem of making different sizes of type; in his words, "the contemporary tendency to obtain 7-point fonts by 70% reduction of 10-point fonts has led to a lamentable degradation of quality."

Atta boy, Knuth — now you're on the right track. Why not show some examples of what the computer can do in this area, and other areas of comparable relevance?

Perhaps he will at some future date.

David Ford
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Lincoln, MA 01773

Here are three letters on the Meta-Font, all from the heart.

Editor:

The concept of the Meta-Font attacks all the sensibilities of professionals who work with type. How dare you trade a sensitive brushstroke for a digital grid? The problem with the Meta-Font is that it will be available to amateurs, and together they will set written communication back to a new dark age.

Angrily, Gary Gore

Editor:

A pox on those who worry about the Meta-Font. It will do to typography what plastics have done to industrial design — give the art a new dimension and new freedom. We are not limited, for instance, by quite another. CAD is neither good nor bad but using makes it so.

Ed Fisher, Jr.
Carnegie-Mellon University
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P.S. What is needed now is not more alphabets, but a sophisticated reading device that will continually read 3 or 4 characters to determine appropriate kerning and spacing. We have long needed th as a ligature for "the." The British established qu, even with swash q's so "queen" could be set gracefully. A sentence ending in l followed by a sentence beginning with cap I creates a narrow space when compared with a sentence ending in y and the next beginning with cap A. If the spacing of the thousands of existing alphabets could be properly controlled to at least equal the spacing of the best hand-set foundry type, then some of the need for new faces would diminish. Safety and good gas mileage are more important in auto design than styling changes. Just as the public have rejected the big Detroit car in favor of sensible economy and performance, we need to worry more about typography — readability and legibility — rather than novel letterforms. The other enemy of good typography has been the mania for speed in production equipment. How many times can huge expenditures for capital equipment be made? The old equipment is of little economic value, yet the design shortcomings remain. E.F.

either Melmac dinnerware or Waterford crystal. Rather, each finds its appropriate place in our society. The Meta-Font will simply become another tool, and probably a useful one at that.

Progressively, Gary Gore

Editor:

Your article exaggerates the importance of the Meta-Font. Because it can be done, it will be done. But after all, both Baskerville and Souvenir were designed by human beings. The computer can do no better than the former, and surely no worse than the latter. The art of typography will survive nicely. Except for the fact that the word Metafont is improperly hyphenated, I see no harm in it.

Cordially, Gary Gore
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To the Editor:

Seen from the viewpoint of typefaces one can recognize three stages — design, technical production, and application in printing — before types are read. The design is performed by individuals (calligraphers, type designers), the production of type faces by groups (e.g., type studios, font departments of manufacturers), composing and setting of texts by a whole branch (e.g., printing companies).

Composing and setting has been computer-aided manufacturing (CAM) for quite a long time. From page make-up to control of printing machines, computers are helping to manipulate and transport data, to expose films, to print letters.

To the Editor:

What is the IDEA behind a metafont if the design looks like a reader's nightmare?

Frutiger is quoted, but Frutiger does know something about typeface design and computers and has achieved something valuable and readable.

Visible Language gets carried away to the farthest shores of esoteric mind-play, at times!

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To the Editor:

I wish to congratulate Donald Knuth and you on this significant contribution to the development of typographic art. The well chosen and very fitting term "Meta-Font" is bound to play an important role in future literature about type and type design. Computer-aided design of letterforms opens up new avenues in the production of typefaces and saves type designers and manufacturers time-consuming manual drawing work. The article provides a scientific foundation for a working method which has already proven its practical value. Especially the proposals for constantly improved and strengthened parameters of certain experiences regarding the legibility of text types deserve attention.

Unfortunately there appears to be a contradiction which dampens the euphoric expectations when one considers the practical results of typefaces drawn with the aid of a computer for photographic or digital composition. Of the many variations which the author derived from the

Since 1975 the technical production of typefaces has been automated partly by systems like the IKARUS-system. According to the frame of technical requirements the concept of IKARUS is, for example, to follow the given design of a typeface. The edge (we call it contour) is digitized by hand as accurately as possible for human eyes. Only those variants are programmed which stay in the type family, like slanted, rounded, inlined, outlined, shadowed, expanded, condensed, and antiquated versions. The computer converts from digital contour data to all kinds of digital formats such as vector, formats, nibble codes, splines, running length codes, or bit maps. One has an application of computers which is as well computer aided (technical) design as computer aided manufacturing of typefaces (CADM) in a frame where one has to link original design and printing.

Up until 1979 there has been no real computer aided design (CAD) for designers. Donald Knuth has succeeded to find a brillant solution by his inventiveness and by analysing existing programmed approaches Furthermore, Knuth has analysed the traditions of type design and has programmed them. So, if you would say: "By Meta-Font we will slip away from our traditions," I would answer: "The programs in Meta-Font will behave like moralists, like programmed guards of traditions."

Knuth has made a very human concept. Meta-Font allows the designer to be supported very nicely in finding an expression of his ideas. I think that the designer will take the following way while making a meta-font: First he sees only a few basic Monotype Modern Extended, not a single one achieves the status of an improvement over the original. And of many thousands of photo and digital typefaces which saw the light of day during the past decades, relatively few will be aesthetically valuable enough to become part of the history of typographic art.

When George Forsythe wrote "The question 'What can be automated?' is one of the most inspiring philosophical and practical questions of contemporary civilization," he was equally correct as Knuth with his statement, "In fact, research in artificial intelligence has shown that computers can do virtually any task that is traditionally associated with 'thinking,' but they have great difficulty accomplishing what people and animals do 'without thinking.'" Thus the functions and the limitations of computer involvement in the design of new typefaces have, in a general sense, been established; however, much detail still has to be explored and defined. The areas of aesthetics and of artistic expression can only be viewed in relation to an individual's personality and his relationship to the specific time in history and its society. A programming of such intrinsic values presents insoluble problems to a computer. Nevertheless, certain aesthetic findings regarding legibility, some of which have yet to be scientifically established, can successfully be utilized by computers. The surprising advantage of computer-assisted design equipment is that it can speedily explore the variation possibilities of a type family. But the control over the offered weight and width variations, such as semi-bold, bold, conforms in his mental eyes, then he analyses his imaginations by using Meta-Font to conceive his meta-font. After having programmed his meta-font, the designer is free in choosing parameters in fine steps to find the right expressions for his idea, and this in digital form.

By his meta-font the designer gets a help he hasn't had before: he is able to analyse his ideas, and he can test the legibility of variants by himself and with others in a very short time.

We have had discussions since the ATYPI meeting in Warsaw (1975) about an undesired multiplicity for typeface families. The German type designer G. G. Lange has said: "What you will produce reminds me of straight streets having rows of poplars on both sides, boring when looking down to the end of that street." In the meanwhile IKARUS has been used by many manufacturers. As a rule the ability to vary typefaces has been used very conservatively.

I can imagine that one will confront Meta-Font with too many variants again. But the designer has to look upon the variants as an offer, he has to make the right single choice. The final forms of a typeface are specified by legibility, esthetics, and prevailing taste; all three are imbedded in our culture, guaranteeing appropriate letterforms.

Meta-Font is an expression of our time: not only computerized, perfect and demanding, but also humanistic, useful and supporting human values.

Peter Karow
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densed, expanded, bold expanded, etc., has to remain the prerogative of the designer, who also needs the opportunity for manual modifications on the letter contours.

Knuth is absolutely correct in stating that programming the computer requires systematic thinking about interrelationships which had previously been solved by common sense and "feeling." The old punch-cutters possessed rich experience and fine sensitivity for harmonic relationships in letterforms. One should try to computer-program their knowledge which had been gathered over centuries and filtered through praxis. They knew about stroke width compensation to achieve a uniformly gray appearance of the type. And it should be possible (as Berthold has accomplished with their so-called aesthetic programs) to program small caps in such a way that each combination of letters appears optically well spaced. The same should be required of all-capital settings.

The author has already covered a series of parameters which are significant for each type design. I would like to call attention to further questions which should be lifted out of the area of graphic feeling into the limelight of scientific knowledge:

1 By what percentage of over-all height does the optical center stand above the geometric center?

2 By what percentage should the diameter of a circle be larger than the depth of a square so that both appear to be optically of equal height?

3 What percentage of the body size of a letter should be allowed for diacritical marks above capital letters?

To the Editor:

It would require a lot more time than is presently at my disposal to produce an adequate comment on Donald Knuth's article, "Concept of a Meta-Font." A few reactions may be set down and sent off simply to indicate a fundamental disagreement and to record a number of areas in which this disagreement becomes most evident. Knuth is obviously not a type designer; I seem to recall that he made a point of studying typographic history — in what depth or sequence was not clear. What is clear is that he is a mathematician with curious and even superstitious beliefs about the relation of man to the computer.

It has usually been the mathematicians who were bitten by the idea of controlling language, of which type is a necessary adjunct. Gottfried Wilhelm Leibniz, the mathematician, tried his hand at a universal language and a universal type, starting about 1666, and was occupied with the project for all of his life. His fame, happily, does not rest on this aspect of his work — both the language and the type remained dead ends. In 1692 Louis XIV of France ordered a type for the Imprimerie Royale that was to be exclusively for the use of that printing office. Members of the Academy of Sciences under the leadership of Nicolas Jaugeon, who thought they knew something about such matters, came up with a design based on 2304 little squares. Each letter and sign was to be plotted on this grid. Philippe Grandjean, the punch-cutter paid little attention to the 2304 squares; but he did concede that Nicolas Jaugeon's dictum,

4 Should the stroke width of small caps be equal to that of lower-case letters or slightly thinner?

5 Should the stroke width of lining figures be adjusted to capitals or should it be identical to that of the lower-case characters?

6 What is the thinnest possible stroke width of a newspaper text face?

7 What is the smallest possible counter of a 6-point type?

This is merely the beginning of a long array of questions which are of importance for the legibility of a text typeface. Once we have answers to these questions, the computer could be programmed with some aesthetic values.

Punchcutters, of course, also knew that smaller point sizes had to be expanded in shape and stroke width while larger sizes had to be condensed. Most photographic and digital typesetting systems are limited to a single (or at best to three or five) fontmasters and therefore achieve rather unsatisfactory results. Technologically it should, however, be possible to provide each point size with its optimal shape and stroke width.

Manufacturers of typefonts must not be satisfied with the issuance of a maximum number of alphabets which are therefore frequently immature in their design features. With the cooperation of experienced, well-known type designers they should be able to create letterforms that are at least equal to the beautiful types of the metal typesetting period. Superficial multiplicity of forms may initially receive aesthetic credit; but it is short-lived, because readers will demand true typographic quality.

"the eye is the sovereign ruler of taste," was a good basis on which to work; so he and his student, Jean Alexandre, produced the first series of punches for the "romain du roi." A number of leaps brings us to the present in which Knuth and others fancy that a typographic design can be patterned on a grid of some sort, and that all the sizes can be mathematically calculated; the eyes have nothing to do with the problem anymore.

In 1966 the Munich Akademie sponsored a symposium on the theme, Art in the Age of Technology, that would be very good reading for anyone concerned with the present situation; the papers read by the participants were issued in a book published by the Academy for the Graphic Industries. The drawback is that the book is in German; still, it is worth scrambling through the notions of Heidegger, Heisinger, Guardini, Friedrich Georg Junger, and others in order to achieve a point of view and some philosphical understanding of the matter. This has not changed much in the fourteen years that have elapsed: linguists, philosophers, and artists remain in the position of polite skepticism while the technological people have become more brash, cocksure. The former feel, perhaps, that the mathematicians and pseudo-scientific computer enthusiasts will come to the end of their pipe dream sooner or later. That Knuth is such an enthusiast is abundantly clear; the whole tenor of his badly-designed and distressingly-written article could only come from an addiction to the sort of technological booze that is currently considered a requisite for the advanced thinker of

One should explore how the advantages of speed and variation productivity inherent in computer-aided type design may be combined with artistic expression and with a craftsman-like sense of responsibility. Knuth has shown a valid path, nevertheless, the results cannot satisfy until they can be measured against those standards of aesthetic quality which have evolved over centuries.

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Translation by Klaus Schmidt.

To the Editor:

A hearty salute for printing Donald Knuth's Meta-Font article. For the first time we see a product of metafont that is sufficiently professional to turn us on rather than off. The numerous illustrations give a glimpse of the computer's enormous potential for variation. It would be truly mind-boggling had we not come to assume, naively, that there is no limit to what can be expected from a properly programmed computer.

What Knuth has done and will do is a tremendous contribution to the multiplication of letter designs, and we should all be deeply grateful for it. One reason it is so significant is that most of the letters we'll be reading in the future — whether in print or on video — will be constructed digitally: they will be made up of very tiny "bits" or "pixels," and Meta-Font, as I understand it, is the pen that draws with pixels rather than with ink. To manupulate the pen you must initially direct it by means of a keyboard this era. The George Forsythe quote in his article gives the measure of the man: " 'What can be automated?' is one of the most inspiring philosophical and practical questions of contemporary civilization." To me, it is clear that Knuth is not only not a philosopher but also not practical.

In 1814 Georg Joachim Goschen, the Leipzig book printer, made a considered statement to Friedrich Koenig, the inventor of the cylinder press, who had tried to interest him in its manufacture and distribution: "Your press will produce many impressions but nothing beautiful." I would say that the Meta-Font system may churn out an infinite number of "designs" but nothing beautiful. It is quite proper that Knuth is being supported in his endeavors by the National Science Foundation and IBM; the latter, after all, sells computers and the former is always ready to support the confreres in far-out but "practical" research.

It must be clear from my remarks that my disagreement with the Meta-Font is profound. For anyone who has devoted a good part of his life to type and letters there is just nothing there, except the possibility of infinite distortion of what was a rather poor type to begin with. Even if the basic letter were to be produced by a superb designer, the variants would be distortioins immediately; photo-lettering called these variants modulations and modifications — a polite pair of names for distortions. The basic reason for the single types and sizes of the great private presses was the possibility of perfection. It was still the eye being "the sov- using Meta-Font language. Having instructed the "pen" precisely how to draw each characteristic of a particular font, it will then, under your direction, magically redraw the font in a hundred or a thousand family variations — some of them tenth or twentieth cousins of the original — and you can pick the one you like best, if any.

It is the "if any" that may be the Achilles heel of Meta-Font. I say this because I would have supposed that somewhere in the article's numerous variations of Roman Extended #8 we would have been shown a modification with typographic values that made a better typeface than Roman Extended itself. Unfortunately that it is not the case. The modifications are different, but not better in important ways. Knuth suggests that a better designer at the keyboard could be counted on to produce better results. That remains to be seen. There is no guarantee that a keyboard is more conducive to creativity than a pencil. Which leads to an all-important question: Is it asking too much to expect a mechanically generated derivative of a carefully thought through artistic concept to exceed or even to equal the original from which it was derived?

Fifty years of experience in photo-lettering may shed some light on this question. I have found that when a well designed type style is altered photographically, or even by hand, to make it conform to exacting parameters of space and color, it usually serves the immediate purpose with merit but rarely measures up to its unaltered progenitor in those characteristics that would make it a better typeface.

ereign ruler of taste." Technology has little use for this human aspiration; every aspect of it leads away from the human and the divine, and the designer ends up talking to his computer.

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To the Editor:

Yes, it is possible to program a computer to design a typeface. Without considerable human intervention, however, it is questionable whether the result would be adequate from a quality viewpoint or economical from a commercial standpoint. Knuth's article was typeset in a face called Computer Modern Roman. which has 28 design parameters plus 3 inter-letter spacing parameters. To my knowledge, no one has as yet tabulated the number of design and visual decisions made by a human designer in the process of making a new typeface, but I would venture to predict that it would be in four figures. This seems self-defeating. Designer + programmed computer, however, when working together opens up an entirely new situation and one that could prove advantageous to both. It would lessen considerably the programming and storage needed by the computer and save valuable time and effort for the designer. In effect, let both do the part that each can do most efficiently. At the output end of a digital typesetter you can visually see the end result of changing the x-y ratio, the angle density, etc. All of these electronic

Then there is the other question: Who decides whether a derivative is or is not better? Some years ago I attended a meeting between local naturalists and the New York Central Railroad in which the naturalists chided the railroad for disfiguring the Hudson's shoreline with its tracks. The railroad representative, for his part, insisted that the tracks had really added to the charm of the shoreline by straightening it out!

Or consider Beethoven's Ninth Symphony. It would certainly be possible through electronic magic to play a recording of this great work faster, or slower, or in a different key, or backwards, or amplified to shake the rafters, or perhaps in a different rhythm, or even altered acoustically so that the bassoons played the violin parts and vice versa. Out of several million combinations it is possible, though not certain, that a better performance would emerge. Yet there is another way — a less iffy way — to get a better performance of Beethoven's Ninth: call in a better conductor.

We do indeed need better typefaces; and we need to make the most of the skills of our few accomplished type designers. We need better Caslons, better Goudys, better Bodonis, and better Roman Extendeds as well as better and more creative concepts for better legibility on the video screen. We particularly need good tools to make better letters from pixels. Meta-Font may well be that tool. It surely has a role in the future of letter design. But at some point Meta-Font will have to bite the bullet and face the bitter fact that neither more nor different are and/or optical changes leave something to be desired visually, but if edited by a skilled designer they can save considerable time, and in some interactive systems it allows the designer to more carefully integrate the changes that occur in creating a full family of weights and widths.

As a side effect the exercise involved in developing Meta-Font may open up new programs and potentials that could be used by a type designer on an inter-active console. These fall-out developments would most probably never happen if the basic R&D for Meta-Font was not done. As a matter of priority, however, I would put the needs of typography ahead of the needs of type design. Time spent to prove that a computer can design type reminds me of the attempts to construct an alphabet geometrically by Durer, et al. This time could be better utilized by using it to adjust space for better legibility, and in other ways that typesetting can be improved by electronic means.

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To the Editor:

I do agree with Donald Knuth that knowing parameters can be useful, but we differ in opinion on how to get them and to what end they can be used.

With some sheets of paper, a pencil, and an eraser the idea for a type design can be fastened down quickly. With felt-tipped pens camera-ready drawings are made in necessarily better, and that what we need most of all is better.

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To the Editor:

Donald Knuth's admirably clear description of his remarkable Meta-Font language for letter design might, through no fault of his, be misunderstood by some readers. Before I say why, let me offer mild comments on two points in his text. First: the sans-serif letter is not modern in the time sense, and to transmute a seriffed type into a sans-serif does not make the type grow "younger" (page 17); it simply changes the type from one class to another — as the use of scissors and razor enables a man to change from the class of bearded men to the class of the clean shaven. Second: it is not quite the case that "five centuries of typographic practice have witnessed a continual craving for new alphabets and for large families of related alphabets" (page 22). The ordinary printer has usually regarded the purchase of new typefaces, often at the whim of an importunate customer, as capital expenditure of doubtful wisdom. It is the manufacturers of type, the founders and composing machine makers, who for commercial reasons have been responsible for creating new faces, and publicising them not only to printers but to those who can influence them. The advertisement typesetter is a separate case, a specialist who did not exist before the twentieth century; he a short time, to be reduced and reproduced photographically in an instant. Modern glues allow the designer to paste together a trial text fast, that again can be reduced to text sizes and reproduced instantly. In this way I can get a presentable representation of an idea for a type design in about two days.

Electronic drawing systems like Logica/BBC's Flair or Quantel's DPB 7000 could be faster if some printing system were tied to it, but such a hurry is not really necessary. The advantage of using an electronic drawing system is, of course, that the registered design can be fed easily into an electronic typesetting machine and set in a number of point-sizes, with different leadings, mixed with other faces, etc. Such a system also allows the designer to try out more variations than he is able to with pencil and paper. All this can make it easier for the designer to judge his work.

Of the drawing systems now available, I prefer those that help me think rather than those that make me think. Besides being a designer, I have no objection to act as a systems operator, but I don't want to become a programmer — even less a parameterizer.

In the beginning of his article, Knuth gives the impression that the parameters of a design are more important than the design itself — that is: than the idea behind the design and how the face looks and reads. (The art of letter design will not be fully understood until it can be explained to a computer.) Towards the end of his article this opinion is adjusted, but still parameters are over-emphasized. I don't think that the gist of a type design can be willingly buys any new type, knowing that there are typographers who think, naively, that the use of the latest face automatically ensures an effective advertisement. And as to large families of related alphabets: the Caslon variants, and the Cheltenham and Bodoni families, were not really typical of the bulk of typographic creation; and the present habit of producing a variety of weights (more than are really needed, it often seems) is no more than people taking advantage of modern technology to create an artificial appetite for their wares.

Although careful reading of Knuth's article makes it plain that he claims nothing more for Meta-Font than that it is a splendidly versatile means to an end, I fear there may be those who think that from now on typefaces will be created by someone sitting at a keyboard and fiddling with the Meta-Font parameters until, with a cry of "Eureka!" he or she announces the immaculate conception of a new typeface. Not so. The type designer with a proper understanding of his role will, in the future as in the past, first decide upon the area of printing in which he intends his type to serve, recognise the degree of output quality he can expect, work out on paper the characteristics which will give the face its distinction, and then use Meta-Font to help him develop the design more rapidly than would otherwise be the case — and doing so with conscious gratitude to Knuth for devising such a useful aid.

What the designer will not do, one fervently hopes, is to adopt the standpoint expressed by Kurt Weideman on page 49 of the same issue found in its parameters. If one wants to study Dwiggin's Caledonia, his thin paper drawings and Mergenthaler's working drawings will yield virtually all parameters. But the heart of the design is found in Dwiggin's short introduction to the Caledonia specimen of 1939. How will I tell the computer?

A curve can be either limp, or, as Dwiggins called it, show "whip-lash action" — a distinction made on the basis of a visual observation. Figures can help to sharpen such statements. What happens if parameters, or "identical form ele-

of Visible Language: "There is no need to design new alphabets for aesthetic or stylistic considerations" — a curiously arid view to be held by a professional designer. On the contrary: whenever a designer has an opportunity to make a thing look attractive, he has a duty to do so. At this stage in time it ought not to be necessary to say that all designing — whether of a car, a coffee pot, or a typeface — is a process in which two aspects should combine and balance: the object must work well, and it must look well. To eliminate the pleasurable aspect from a typeface and deal with functional requirements only will inevitably result in a lifeless design which might just be tolerable in a work to be consulted, like a directory, but will be a dispiriting experience for the reader of a book.

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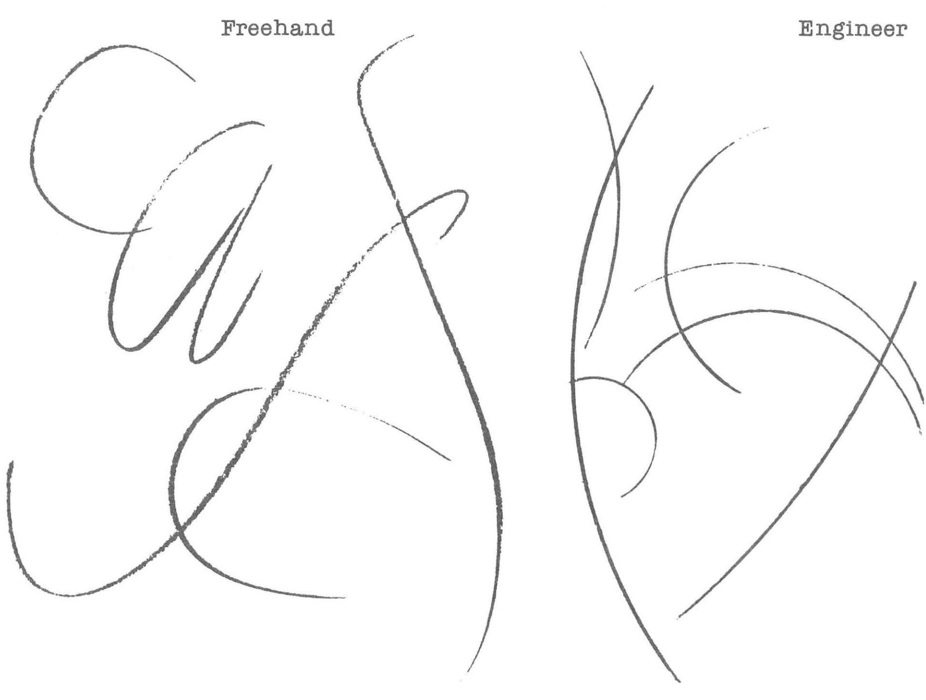

From a document dated February 22, 1937, wherein Dwiggins criticizes Mergenthaler's newsfaces, like Ionic and Excelsior. He found them too rigid, obviously constructions of engineers, and he made proposals for livelier designs.

ments," are allowed to dictate a design is shown in the Bible face in the same issue of Visible Language (pages 51 and 52); it becomes awkward, or — another expression of Dwiggins — "engineery." Although development over 500 years has led to highly formalized printing characters, type design still belongs in the domain of the visual arts.

The urge to parameterize is, like Diderot's and d'Alembert's wish to describe and catalogue, a rational aim. And it is no coincidence that in the age of Rationalism the first Meta-Font — or rather, type family — was created by Fournier.

But type families have limitations. Of many such related designs now offered to the trade, too many are little used. They are only of use if they present a strong enough visual differentiation. It has turned out that there is a discrepancy between what is practical and an aesthetic's wish to get a nice gradation from light to black. Also I would call the hyper-modern sans-serif beginning on page 16, a different design from Computer Modern. (Don't shapes like these belong to the period when Eurostyle failed to become a success?)

I do agree with the author that "in the long run the scientific aspects of Meta-Font should prove to be the most important." But to what end? And in what way will parameters be collected? If parameters can be registered while using an electronic drawing aid (as described earlier) and can be extracted afterwards, I would prefer that to setting them beforehand. As for their use, among the possibilities I've set some hope on, one is that legibility research can be much refined and made more useful to designers.

To turn again to Kurt Weidemann's article on Biblica: on page 52 he states: "the strokes of typefaces are generally too heavy, particularly in conjunction with mediocre printing quality." Too many research results flatly contradict him. On the other hand, the 9-point text shows at first glance that spacing between the characters is irregular and too wide. What is too heavy and what is too wide? The comparative study of parameters could lead to precise statements and more exact design briefs. We could then design, for example, type families with members of useful and strong enough visual distinction.

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To the Editor:

The Meta-Font system as described by Donald Knuth shows the endless possibilities of this computer-aided approach to type design and should not be examined or analyzed merely for its aesthetic values. The demonstrations by Knuth are visual explanations of the system's potential.

The transformation from a roman into a sans-serif face within 26 lines on page 15 is a graphic example of the ways in which it is possible to manipulate 28 variable parameters. The system, however, is still in the processing stage and several structure-oriented refinements remain to be added. I would recommend that a more precisely controlled software structure be developed which might also include room for any additional tricks. In other words, the system as it is presently conceived needs some aesthetic limits: besides the "pens" and "erasers," in Knuth's terms, we also need "brakes."

I would not want to slow down the imagination of a user, but during the continuing development of the system we should avoid the dangers of producing poor results by indiscriminate deformations of letterforms. Let us hope we can keep control of the manipulations of letterforms in the coming years. Perhaps fewer designs but better designs.

As soon as the final program concept of Meta-Font is available, it may be necessary to expand the 28 basic parameters; frameworks of Meta-Font standards should be developed which are in the form of menus or modules. These "menus," or lists of choices within a particular program, would be especially useful for people who are not trained designers.

The Meta-Font system is not designed to copy nineteenth century typefaces because it does not precisely follow an outlined fixed drawing. Meta-Font in the hands of a creative designer is a versatile tool for making experimental character modifications; such a computer-assisted system is ideal for testing new alphabets in order to find the optimum solution for a special design task.

I believe that new alphabets in the future will be increasingly based on thoughtful research and will have a mathematical orientation similar to many of the faces produced in the last 30 years. In effect, the final alphabet is precisely planned ahead. The elements for a new design will be less artist-oriented. The Meta-Font concept has its historical antecedents in such designs as the Romain du Roi of the French Jaugeon commission (1692), the Futura of Paul Renner (1926), or Adrian Frutiger's Univers design concept of 1957. This does not mean that our future alphabets will look antiseptic in their appearence nor will they be cold or strictly mechanical.

There is an increasing need for special alphabets in connection with new electronic printing systems. By means of Meta-Font one may efficiently determine which design or serif shape reproduces best, considering the enormous speeds at which the letterforms are generated. The hairlines may be easily manipulated as well as the distances between characters. Our goal is, and always has been, an easily readable line, one which avoids the illegibility of too narrow intercharacter spacing. We should work for maximum legibility — which is not always the case in these days of word processing and electronic printing. One must bear in mind that the printed text, the end-product which appears on the sheet of paper, is still important, not the sophisticated system in itself or the programs which run the jobs. Within Meta-Font there are sub-programs which are able to check proportions, those frequently forgotten secrets of the old masters which must necessarily be the most indespensible structural element of all new typefaces. The classic structure, developed and refined over the past 500 years, must be the foundation for the really useful alphabets of the future. Those will be neither deformed nor poor copies of existing alphabets.

I believe Meta-Font will stimulate alphabet design. In these days of mass communications many languages in Africa and Asia are still without alphabets. There is a vast area in which creative people may exercise their skills including scientific publications which require specialized graphic solutions. A very good example is the new mathematical font family for the American Mathematical Society, called Euler, which not only includes a new kind of roman, but an upright script, a fraktur, a greek, and more. Meta-Font will not limit designers' creativity, nor will it deprive them of jobs in coming years. Meta-Font is an ingenious computer-based tool worked out for those individuals with less manual design experience.

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A Reply from the Author:

What a privilege it is to have so many distinguished people reading my work, and what a pleasure to read their profound comments! Thank you for giving me a chance to add a few more words to this stimulating collection of letters.

As I was reading the diverse reactions, I often found myself siding more with the people who were sharply critical of my research than with those who acclaimed it. Critical comments are extremely helpful for shaping the next phases of the work that people like me are doing, as we search for the proper ways to utilize the new printing technologies.

One of the most surprising things about the voluminous correspondence I have received about this article is the fact that nearly everybody looks at the Good Shepherd Psalm and calls it the Lord's Prayer. So far only two or three people have identified it properly! This curious phenomenon has nothing to do with the notion of a meta-font, but I can't help mentioning it in case it turns out to be relevant somehow to human literacy.

Several of the letters mention my citation of George Forsythe, and your readers may be interested in further details about what he said. George was one of the first people to perceive the real importance of computer science, as opposed to the mere use of computers, and the remark I cited is taken from the introduction of an invited address on Computer Science and Education that he gave in 1968 at the Congress of the International Federation for Information Processing, held in Edinburgh. I wish I could have quoted his entire article; the best I can do is urge people to look for it in their libraries (Information Processing, ed. by A. J. H. Morrell [North-Holland, 1968], vol. II, pp. 1025-1039).

Perhaps I may be forgiven for citing also another article of my own, entitled "Computer Programming as an Art" (Communications of the ACM, vol. 17 [December 1974], 667-673; L'Informatique Nouvelle, no. 64 (June 1975], 20-27). In this essay I attempt to show that the essential difference between science and art is that science has been codified (and in this sense "automated"), while art is what mankind achieves with its mysterious intuition. My main point is that science never catches up to art, since the advances in science are always accompanied by artistic leaps.

Thus, my hope is that the advent of computers will help us to understand exactly how little we really know about letterforms. Then, as we attempt to explain the principles in such concrete terms that even a machine can obey them, we will be learning a great deal more about the subject, so that we and the coming generations will be able to raise the artistic level even higher.

Meanwhile my experiences since publishing the article in Visible Language have been quite encouraging. Several leading designers have generously given me specific pointers on how to improve the Computer Modern fonts, and I spent the month of April making extensive refinements under the tutelage of Richard Southall. The number of parameters has grown from 28 to 45, but all the parameters still seem to make sense; and the careful incorporation of such subtleties is already yielding significantly better results. Much remains to be done, including further development of the mathematics of shapes, but there now is some evidence that the tools we are developing will not be inadequate to the task. I hope to publish a book that captures the things these people have taught me, so that such knowledge can be widely appreciated, apprehended, and appropriated, not merely applied.

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The Emergence of Visible Language: Interrelationships between Drawing and Early Writing

Anne Haas Dyson

The purpose of this study was to examine the interrelationships between drawing, early writing, and the context of talk in which they both occur. Participant observation methodology was used to gather data daily during a three-month period in a self-contained, public school kindergarten. The researcher set up a center at which the children freely drew and wrote. She observed and interacted with the children to gain insight into their perceptions of drawing and writing. Data consisted of audio recordings of the children's talk at the center, their graphic products, observational notes, and child interviews. Patterns were identified in how the children combined the drawing and writing processes in the production of one graphic product and in how they used drawing and writing terminology referentially across production modes. On the basis of these patterns, inferences were made about written language development. Learning to write was portrayed as a process of gradually differentiating and consolidating the separate meanings of these two forms of graphic symbolism—drawing and writing.

Writing has its roots in the young child's growing ability to form representations of the world and to express those representations through various media. Thus writing, as Vygotsky (1978) stressed, has a role in the history of the child's ability to symbolize. Writing appears to have particularly close ties to drawing, the earlier developed and less abstract form of graphic symbolism. In fact, the letters of the alphabet first appear as art forms in children's drawings (Kellogg, 1970). The purpose of this study was to examine systematically the interrelationships between drawing, early writing, and the context of talk in which they may both occur.

The study was based on data gathered in a participant observation project which focused on young children's verbal and nonverbal behaviors during the processes of drawing and writing. The use of participant observation, or phenomenological, methodology reflects the goals of the study: to describe not only the observed relationships between drawing and writing but also the children's expressed differentiation between these two symbol-producing activities. That is, this study was developed from a view of the child as an active investigator of written language. As researcher I asked, How do young children make sense or conceive of the symbolic process of writing as compared to the process of drawing? More specifically I focused on these two questions:

Visible Language, XVI 4 (Autumn 1982), pp. 360-381.
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1 How did the observed children combine drawing (pictorial symbols) and writing (letters or letterlike symbols) in their work? In other words, what roles did drawing and writing serve in one graphic product?

2 How, as evidenced by their use of drawing and writing terminology, did the children differentiate between drawing and writing? What did they call *writing?* What did they call *drawing?*

Related Research

Both drawing and writing are foreshadowed by young children's scribbling. From scribbling the two forms of graphic symbolism appear to develop in roughly parallel fashion (Brittain, 1979). Early random scribbling develops into controlled scribbling as children begin to guide the loops and swirls. After these initial scribbling stages, children become concerned not only with physical control over lines but also with the relationship between those lines and the objects they might stand for. Thus, between the ages of three and six, children's controlled scribbling gradually develops into recognizable objects which they *name* (Brittain, 1979) and, similarly, the scribbling gradually acquires the characteristics of print—including linearity horizontal orientation, and the arrangement of letterlike forms—which children may *read* (by inventing a text) or request that others read (Clay, 1975; Hildreth, 1936).

Children's first pictorial symbols consist of objects that are meaningful to the child—people, houses, pets, trees, flowers. The drawn objects are not necessarily specified; that is, the child typically makes "a house," rather than "my house" (Gardner, 1980). These objects are generally placed on the page as separate entities, rather than arranged to produce a unified portrayal of one scene. Children's first conventionally written words are also single words, although they are specified; they are typically the names of familiar people (Durkin, 1966; Stine, 1980). However, children also request the names of familiar, although unspecified, objects such as *house, school, pencil* (Dyson, 1981). Like their drawn objects, these names are not necessarily arranged in any coherent fashion.

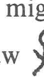
At this point, when a child's products can clearly be categorized as "drawings" (pictorial symbols) or "writing" (letters or letterlike symbols), the inference might be made that the child has completely differentiated the writing and drawing processes (cf. Lavine, 1977). But, is the child producing "written language"? How does the child initially conceptualize writing as a representation of meaning? Does the child view writing, as is popularly conceived, as talk written down (e.g., Savage, 1977)?

Vygotsky (1978) suggested that children's first representations of meaning arise as first-order symbolism: their representations, such as those occurring in play and in drawings, directly denote objects or events. In his view then, in early representational writing, children directly denote entitites through graphics, much as they do in drawing; they do not represent parts of utterances.

The proposed initial relationship between language and writing is similar to the relationship between language and drawing. In both processes, oral language may extend upon or specify the meaning of the graphics; it is not directly encoded into the graphics.

Korzenick (1977) and Dyson (in press) have elaborated on this role of talk in the areas of drawing and writing respectively. Korzenick suggests that young children's drawings cannot be understood apart from the representational behavior (the language and the gestures) surrounding the drawing. She reported that five-year-olds tended to act out and talk through their representations; they failed to differentiate the gestural-verbal-graphic symbols.

Similarly, Dyson (in press) documented five-year-olds using oral language to surround and invest written graphics with meaning. The children's most common type of representational writing was to make names and numbers. Rather than trying to encode speech into graphics, the children typically made meaningful graphics about which they could talk (e.g., "This is my Mama's name.").

Thus both drawing and early writing might, as King and Rentel (1979) suggest, be best described with Langer's (1967) term "presentational" symbolism. To elaborate on that idea, consider how a young child might represent graphically his or her "best friend." The child might draw , and then comment orally, "Joe is my best friend." Or the child might write *Joe*, and then explain, "Joe is my best friend." In both instances the hypothetical child would have produced graphic symbols which could be considered presentational symbolism: the parts of the graphic depiction are not presented successively (i.e., as in language), but "simultaneously so the relations determining a visual structure are grasped in one act of vision" (Langer, 1967, pg. 93). Young children may write *Joe* and be satisfied; adults would ask "Joe what?" because, in discourse, "the name prepares the mind for further conceptions" in which Joe figures (p. 62).

Thus for young children written words may be objects like drawn objects. For writing to become discourse children must become aware that it is language itself which is written. The personal meanings revealed in the talk surrounding the written graphics must assume an explicit, ordered, and linear format upon the page. To again cite Vygotsky (1978), children must learn that one can draw, not only things, but language as well. Given this proposed significance of drawing in writing development, a specification of drawing/writing interrelationships is vital. The present study, then, contributes to such a specification.

METHODS

Site and Participants

In order to gain access to the children's views of writing, I became a participant observer in a self-contained, public school kindergarten located in a southwestern city. The classroom teacher followed the district's kindergarten curriculum, which did not include any formal instruction in reading and writing at the beginning of the school year.

The classroom selected was naturally-integrated and balanced socially, ethnically, and academically. Of the 22 child participants, ten were female; twelve were male. Twelve children were Anglo, six were Hispanic, four were black. At the beginning of this study the mean age of the children was 5 years, 7 months; with a range of 5 years, 1 month to 5 years, 11 months.

From this classroom of children five were chosen for case study investigation. I selected five who, after 15 days of observation, I judged (a) to reflect the classroom's range of developmental writing levels as determined by particular assessment procedures based on Clay (1975) and (b) to willingly discuss their writing with me.

Data Collection Procedures

In order to conserve space I present here only a brief overview of data collection procedures. A detailed description appears in Dyson (in press).

I gathered data for this study daily for a three-month period during the first half of the school year. The data were collected primarily in the morning, between 8:45 and 10:30, during the children's "center" or free-choice period.

Data collection proceeded through three overlapping phases. During the first phase (weeks 1-3) I observed and interacted with the children as they worked in their centers. This unstructured observation period allowed the children and me time to become accustomed to each other — to begin establishing rapport.

Also during the first phase I assessed the children's writing behaviors in order to identify possible case study children. To this end I asked each child individually to "come over and write with me" and then to "tell me what you wrote." Each child wrote a minimum of two times and a maximum of five, with each occasion occurring on separate days. The exact number of writing sessions was determined by my judgment that: (a) the child appeared comfortable with me, and thus I had confidence that the writing could be considered a reasonable reflection of his/her writing behaviors; and (b) the child wrote in consistent styles. For example, if the child wrote in cursive-like script in session #1, and then wrote conventionally-spelled words in session #2, I repeated the assessment sessions until the child produced no new writing behaviors.

I categorized the children into different types of child writers, basing the categorization on my analysis of their written products and their explanations of their writing. I chose five children for case study investigation who reflected the classroom's ranges of types of child writers. The five, all of whom were preconventional writers (i.e., none produced propositional-length messages through the use of an alphabetic writing system), were: Ashley, Tracy, Rachel, Vivi, and Freddy.

The second phase (weeks 3-11) was the major data collection period. During this phase I established a center equipped with paper, pencils, and markers. The center was simply another optional activity open to the children during "free choice" time. I told the children to come write whenever and however they wished. Although the children were invited to come "write," they also came and drew; thus the center, by the children's design rather than my own, became a center for both types of graphic activity.

The center provided access to varied types of data, including: audio recordings of the children's talk at the center, written observations of individual children writing and drawing, children's graphic products, and observations of writing and drawing trends of both individual children and the class as a whole, recorded daily in a research log.

Finally, in phase three (weeks 11-12) I interviewed all 22 children individually about their perceptions of both what is required to learn to write and the reasons for writing. Although I asked additional questions to probe or clarify a child's response, the questions relevant to this analysis were: When (or why) do grown-ups write? When (or why) does your mom or dad write? What do they write? When (or why) do you write? What do you write?

RESULTS AND DISCUSSION

At the end of the eleventh week of observation I had recorded approximately 36 hours of spontaneous talk, collected approximately 500 products, made 112 handwritten observations of individual children, written notations on 377 child visits to the center, and conducted 22 child interviews.

The purpose of this study was to describe both the observed relationships between the drawing and writing processes and, also, the children's expressed differentiation between these two symbol-producing activities. Thus, during analysis of the collected data, patterns were identified (a) in how the children combined drawing and writing in the production of one graphic product, and (b) in how the children used drawing and writing terminology across production modes (i.e., how children used referentially the terms *draw, make*, and *write*, during drawing and writing).

The analysis procedure itself was inductive; it involved classifying and reclassifying data under different organizers. My objective was to detect categories of behavior which would yield a comprehensive description and interpretation of the children's behaviors.

The Intermingling of Drawing and Writing

The first objective was to analyze how the children themselves used drawing and writing. For this section of the analysis I used broad but nonetheless adult definitions of drawing and writing which were based on the appearance of the product. Writing was defined as that (portion of the) product containing letters or letterlike forms. Drawing was defined as that (portion of the) product containing any non-letter or non-letterlike forms. Occasionally, letters (defined by the child also as letters) turned into non-letterlike objects; for example, a sideways *I* became Darth Vader's spaceship. This is intriguing behavior which suggests the close association between the drawing and writing processes. However, for this portion of the analysis, the product was considered drawing because the final form was non-letterlike.

I began by organizing the data into units upon which to base the analysis. The basic unit was the graphic episode. I based the definition of a graphic episode upon the handwritten and transcribed records of the focal children's observation sessions. A graphic episode included any verbal and nonverbal behaviors occurring during the production of one graphic product; it included all behaviors surrounding (i.e., preceding and following) and related to the actual production of the drawing and writing. There were a total of 125 graphic episodes for the five focal children.

I organized the episodes into categories in which the children were combining drawing and writing in similar ways. I then composed descriptors to specify the distinguishing characteristics of that category. The resulting categories and the percentages of children's papers which they accounted for are as follows:

How writing and drawing were combined	N*	%
A Drawing and writing were intermingled on the page; writing and drawing were not related thematically.	60	(62.5)
B Drawing and writing contributed (roughly) equally to the complete product; information supplied by the writing may have overlapped but did not simply label information supplied by the drawing.	15	(15.6)
C Writing served as a label for at least part of the drawn graphics.	14	(14.6)

*29 of the 125 graphic episodes resulted in writing only and were not included in this analysis. Total number of episodes analyzed = 96.

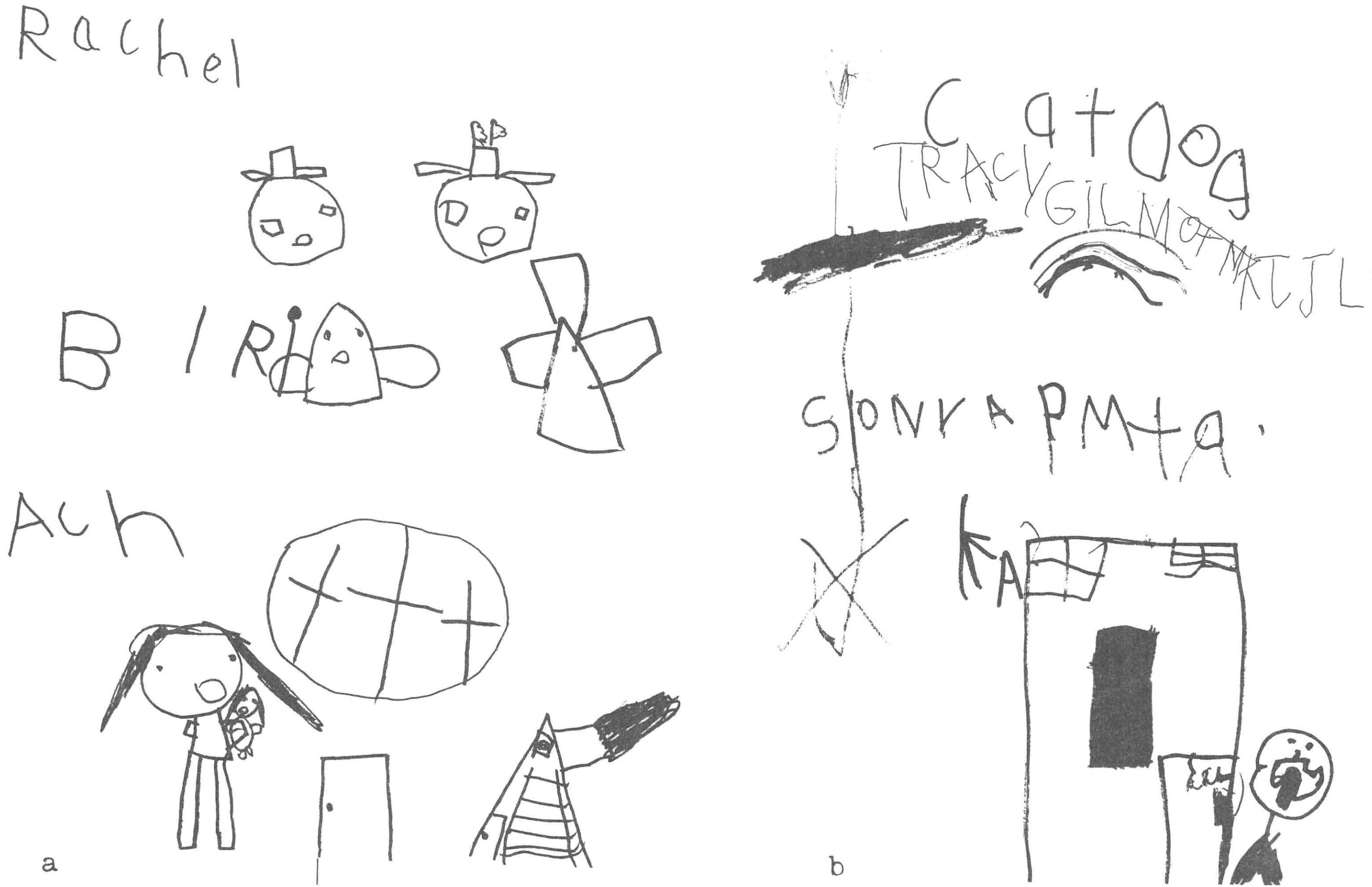


Figure 1. The intermingling of drawing and writing in a nonthematic way.

D Writing was part of the drawn graphics.	6	(6.25)
E Drawing provided the meaningful context for the writing; it was not simply an illustration of the writing.	1	(1)

The intermingling of drawing and writing which were not related thematically (category A) was the most typical type of written product, not only of the focal children, but of the class as a whole. As Figures 1a and b illustrate the resulting products were not organized, coherent wholes. Rather, the children produced a series of symbols on the page.

The order in which children produced the graphics and their remarks about their work clarified the nonthematic relationship. For example, Rachel produced the symbols in Figure 1a in this order:

1 her name
2 the circle containing cross-like marks
3 the butterfly
4 *Ach*, about which she remarked, "That [A] is in my name. That [c] is in my name. That [h] is in my name. If I did the rest of it, it would be my name.
5 a pumpkin
6 "somebody"
7 "her ["somebody's"] dolly"
8 *BIRi*, about which she remarked: "This [B] goes in Brian's name. This [1] goes in my name. This [R] goes in my name. This [i] goes in Brian's name."
9 (the unnamed) triangular-shaped object
10 a house with stairs and a little girl in the window, and
11 another pumpkin

Tracy produced Figure 1b in a similar manner, although instead of letters and objects the product contains written names and objects. The nonthematic relationship between drawing and writing is reflected in Tracy's explanation of her product:

I made a house and I made a (pause) my mother's name and I made a (pause) flowers and I made *cat* and *dog* and my name.

In the remainder of drawing and writing categories, the two types of graphic products *were* related thematically. Figure 2 illustrates the most typical way in which drawing and writing combined in a nonredundant way to form a complete whole (category B). Actually, Figure 2 is a "letter" from Rachel to her peer Vivi. This letter, like most of the letters the children produced, contains the addressee's name, the sender's name, and in this case, a picture of the addressee; the children often wrote letters which contained pictures of other entities, particularly houses and flowers.

Although an atypical occurrence, one child produced a graphic form which was an interesting example of the nonredundant combination of drawing and writing. Vivi wrote *HBO Box*, her word for "Home Box Office Television," as follows | HBO |

Figures 3a and b illustrate category C in which writing served as a label for at least part of the drawn graphics. As was the case in the previously discussed samples, one must consider the children's talk about their work in order to understand the drawing/writing relationship. Vivi explained Figure 3a as follows:

> I got *cake* [the *K* above the word *cake* was an earlier and abandoned effort to independently spell *cake*], rainbow, boat, and a house, and a same thing as this is right there [pointing to a word written on the back of her paper which she had attempted to copy], and I got *flower (VRE)* and I got a flower.

Figure 2. The nonredundant combination of drawing and writing to form a "letter."

Figure 3. Writing as a label for drawing.

Figure 4. Writing as a part of the drawn object.

Figure 5. Drawing as a context for writing.

Ashley's Figure 3b, although far less conventional in appearance, is essentially the same type of drawing/writing combination. The letters in section A of the product are intended as a label for the accompanying drawing. Ashley made the letters after he made the drawing, explaining that they were "the letters of it" — they were the letters that went with the depicted person (his "cousin"). The letters fulfilled, then, the same function as Vivi's *VRE*, letters which went with the depicted flower. The major difference between the two products, beyond Ashley's less conventional letterlike forms, is that Ashley was not exactly sure what his letters said because "I don't read writing."

An example of writing as part of the drawn object (category D) is given in Figure 4, another of Ashley's products. Superman has two *S*'s on his shirt; the letters after the *S* on Superman's midsection were made as Ashley attempted to write his name. The *S* was there simply because, as Ashley said, "Superman always have an *S* on his shirt." Ashley viewed the *S* as a part of Superman.

Finally, Figure 5, a product by Rachel, illustrates category E, in which the drawing provides the context for the written text. More meaning is conveyed in the drawing than in the writing although, as in previous categories, listening to the child's talk was essential in order to understand the drawing/writing relationship:

> Rachel had been drawing the picture in Figure 5 as she narrated a story about two sisters, one of whom had locked the other out: "Sister, open up the door! [Rachel knocks twice on table.] You dummy. Sister, you better come and open this door or else I'm gonna' throw this pumpkin shell on your head."
>
> That's what it's gonna' be saying.
>
> Rachel now wrote line A in Figure 5 and explained to me: It says, "Open the door, Sister. Open, open, open else I'm gonna' throw this pumpkin shell right on your head."

It's clear that the children in this classroom were not combining writing and drawing in conventional ways. That is, they did not write a "story" and then illustrate it, nor did they draw a story as a "prewriting" activity. Rather, they made written names or letters which existed among the drawn forms on the page; typically, the drawing and writing were not thematically related.

Children's Differentiation between Drawing and Writing

To this point I have focused on how the children combined drawing and writing, assuming adult definitions of those terms. At this point I wish to turn to how the children themselves viewed their own graphic activity. To answer that question I focused on the talk that occurred during each graphic episode; that is, the talk surrounding the production of the graphic products just discussed. The graphic episodes as previously defined were based on the work of the five case study children. However, since the children interacted freely with each other at the center, analyzing the talk which occurred during the episodes naturally involved considering the talk of all 22 children.

Even before carefully analyzing the data, the close association between drawing and writing was in evidence. The children frequently interchanged the terms *draw* and *write*, most typically using *write* in situations in which an adult would use *make* or *draw*. In fact, 17 of 22 children used *write* in this way at least once. Further, there was not a linear relationship between the unconventional use of the term *write* and the children's observed maturity as writers. Children of greatly varying degrees of writing sophistication were observed to use the term *write* in unconventional ways.

In order to analyze the children's perceptions of drawing and writing, I studied the data, searching for regularities in the ways the children used drawing and writing terminology across different types of graphic activities (e.g., writing and drawing "letters" for others versus writing a label for a drawn picture). By looking at the situations in which children interchanged terms, I aimed to uncover aspects of *writing's* meanings for children.

I wish to point out here an unconventionality that did not typically occur. Before I analyzed the data I had hypothesized that the children might consider writing like drawing in that they often "wrote" by simply "drawing" forms, by creating appropriate-looking graphics with no apparent concern for communicating a specific message. However, the children rarely referred to any letterlike forms as *drawing*, nor were non-letterlike symbols referred to as *writing*. However, the act of producing a non-letterlike form might be referred to as the act of writing. When did this happen? What might *writing* mean to the child?

On the basis of my analysis, writing appeared to have several meanings which overlapped those of drawing. Both serve: to grahically represent people, objects, or events; to create a graphic object for another; and to graphically represent a narrative. In the next sections, I illustrate each of these meanings.

Writing: Representing Entities

As noted in the discussion of Figure 1, the symbolizing of people and objects was the most typical representational writing done by the children in this class. Similarly, the most typical unconventional use of the term *write* was in reference to the drawing of an object, as in "I'm gonna' write him pants." If one excludes discursive written language, drawing and writing become quite similar, differing simply in whether or not one uses letters or pictorial symbols to denote the object. Generally, I could tell if a child planned to write the label or draw the pictorial representation by noting the presence or absence of the article *a*.

In two writing episodes the importance of the article was dramatized. The first episode involved the only instance of conflict among the children in regard to this use of *write*; the child whose competence was questioned actually intended to write but had inserted an article in an inappropriate place:

Courtney I'm gonna' write a horse and um I don't know what I'm gonna' write today.

Linda *Draw,* not write a horse, *draw* a horse.

Courtney I'm gonna' spell it.

The second episode involved the only instance of intrapersonal conflict; one child, Mark, again seemed to be deciding as much on the use of the article *a* as on the use of *write* or *draw*:

Mark (to Dyson) I wonder how you draw *star*. No, I wonder how you write *star*. How do you write a star—not *write a star*. I mean . . . let me copy it. (Mark wants me to write it.)

In both these excerpts *write* was used in reference to symbolizing objects. To more clearly illustrate this pervasive association between writing and concrete entities, I include the following two episodes involving two other class members: Damon and Kevin.

Damon had been drawing the picture in Figure 6. After he was finished I began to interview him about writing. I asked him what his parents wrote and what he wrote. He then explained to me that, although his parents wrote, "I just write houses and stuff." The use of the word *just* implies that Damon knew that sort of thing, drawing, wasn't what I had in mind. A few minutes later, Damon volunteered to try to write:

I'm gonna' try to write *church*. You know how to write *church?* Write it on a little piece of paper, that little bitty mouse church (pointing to a small church he had previously drawn on his paper.)

When Damon asked me to write *church* for him, he had in mind "that little bitty mouse church." He seems to say, "write that church on my paper for me," as though writing were a matter of making letters for objects, which are then read as the names of those objects.

Damon's peer, Kevin, provided another illustration:

Dyson What are you writing, Kevin?

Kevin I'm writing this flower. (See Figure 7; Kevin writes letters around flower.)

Dyson And now?

Figure 6. *Writing* as the representation of a specific entity: "Write . . . that little bitty mouse church."

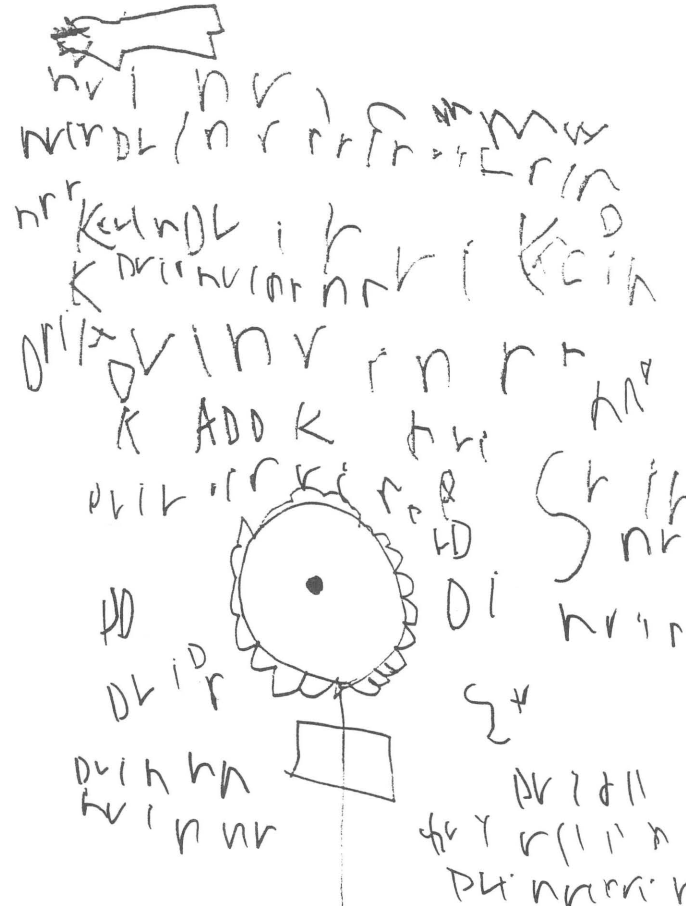


Figure 7. *Writing* as the representation of a specific entity: "I'm writing this flower."

Kevin I'm gonna' spell that little dot on it. (Kevin adds more letters for the "dot" in the middle of the flower.)

Kevin later explained that he had written, among other things, *little flower* and *dot.*

Although their comments are particularly revealing, both Kevin and Damon are representative of the children in the observed classroom; their use of the term *write,* whether in reference to the production of pictorial or letter symbols, demonstrates the association of *writing* with the representation of concrete entities.

Despite the frequent use of *write* to refer to both pictorial and letter symbols, in the interview situation, in which I directly asked the children about writing, they seemed aware of the differences between how they "wrote" and how adults "wrote." When I asked them what, when, and why adults write, they most typically told me that adults wrote words and letters, as in *G, Q, M,* because they want to. On the other hand, they said they wrote their names and the *ABC'S,* although seven of the 22 children told me that they only drew ("All I like to do is draw," or, like Damon, "I just write houses and stuff.").

Thus, although most of the children occasionally substituted *write* for *draw,* they did know that writing, at least in the adult world, resulted in a product containing letter forms as opposed to pictures. There was a context, however, in which the children seemed to genuinely view drawing as *writing.* This context was the production of what the children alternately referred to as "notes," "letters," or "presents."

Writing: Creating Objects for Others

When adults write letters, they write messages; however, children's letters often consist of pictures. Consider the following excerpt from an interview with another class member, Shawna:

When does your mom write?

She writes every night. She writers letters to my Grandma, and my Grandpa, and all my friends.

What does she write in the letters?

Like, we're gonna' have a baby. . . .

What do you write?

Car, pen, house, box, paper, pencil. . . .

When you write a letter to your Grandma, what do you write?

I write my name, and I write pictures for my Grandma.

Shawna's remarks gained new significance as I reflected upon the "letters written" by the children in the room. The children's letters contained no particular message; typically, they consisted of the names of the addressee and the sender and a picture (see Figure 2). Their writing of letters, alternately referred to as "notes" or "presents," involved primarily making graphic objects for someone else, and, indeed, making something for someone else *is* an aspect of writing letters.

I will illustrate this view of writing as creating graphic objects for others by briefly discussing an excerpt from one of Vivi's graphic episodes. To appreciate the significance of this episode, it is important to bear in mind that Vivi, relative to the other children in the class, clearly distinguished between drawing and writing. She was atypical in that she never used *write* to refer to drawing particular entities. Further, she clearly attempted to write spoken words which in turn stood for objects (i.e., she attempted to go from formal characteristics of the oral utterance to particular written graphics; for a discussion of her style, see Dyson, in press). Nonetheless, Vivi did use *writing* in reference to *drawing* when she was producing a "note" or a "letter" for someone:

Vivi (Vivi was drawing a picture.) I'm writing notes.
Dyson When?
Vivi Now. I can't wait to give this to Ms. G. [classroom teacher].
(Vivi takes the note to Ms. G., returns to the center and remarks: She love it.)

Although this use of *writing* for *drawing* may seem strange, one need only recall the many notes one has written, not with anything in particular to say, but simply to get *something* in the mail to someone one wishes to stay in touch with. Although Vivi was drawing, she was creating a particular form for a particular person in order to touch base with, and to please, someone important to her.

Writing: The Representation of a Story

A final use of *write* for *draw* occurred in the context of a child telling a story as he or she drew. This use of *write* for *draw* differed from writing as the representation of a specific entity only in that, in the present case, the entity represented had a role in a larger piece of discourse. The following narrative, told by Rachel during the production of Figure 8, illustrates this use:

Rachel He's pushing her mom because she wouldn't hurry up. Her little boy was pushing her because she wouldn't hurry up. And she couldn't find the door . . . the way to find that Christmas tree. She was trying to get to the other side to get her little baby. There--see that's her little baby . . . and she was trying to get her 'cuz she might get hurt. She's just a little bitty girl. And they saw--No, I don't know how to write that.

I had overheard Rachel's comment and so I intervened:
What?

Rachel I wanta MAKE a Rudolph, not write it.

Although this use of *write* for *draw* occurred relatively infrequently, it is significant as, in this case, the drawing is taking form within an oral narrative. In other words, discourse is being represented by a global form of representation, a drawing. Rachel, in talking about her picture, did not say, "This is the mother. This is the little boy. This is the door." Rather, she told an evolving narrative which she, in a sense, "wrote" down.

SUMMARY AND IMPLICATIONS

My analysis of the children's products and the talk surrounding those products indicated (a) the predominantly nondiscursive nature of the children's writing, (b) the lack of symbolic redundancy in the children's representational products, and (c) the tenuous line between drawing and writing for these young children as reflected in their frequent interchanging of the terms *draw* and *write*. These findings concerning both how children combined the drawing and writing processes and how they talked about what they were doing are examined more closely in the following sections.

Figure 8. *Writing* as the representation of a narrative.

How do children combine drawing and writing? In the observed classroom the children's writing was frequently intermingled with drawing in a non-thematic and nonredundant way. As is typical of young children, their pictorial symbols consisted of familiar and meaningful objects--houses, people, pets--placed in what seemed a random arrangement upon the page. Amidst these objects the children put familiar and meaningful letters and words which were not necessarily related to the drawn objects.

What's "drawing" and what's "writing"? For the children themselves a thin line appeared to exist between drawing and writing as evidenced by the frequent use of the term *write* for *draw*. Interestingly, when asked about adult writing and then about their own, the children appeared to clearly understand that, in the context of adult writing, they could write primarily their names and the *ABC's*. Why, then, did they frequently use *write* for *draw*?

In answer to that question, I suggested that, although the written and drawn graphics were clearly different, the processes themselves were not: when the children were involved in graphic activity, the distinction between the processes did not appear critical. Further, it should be noted that the children in this study were engaged in both processes in a non-adult-structured situation (i.e., an adult did not guide or organize their work, as in, "Now that you've drawn, Jesse, let's write about your picture.")

By looking at the situations in which the children interchanged terminology, I aimed to uncover aspects of *writing's* meanings. From this analysis *writing* appeared to have several meanings which overlapped those of *drawing*: to graphically symbolize a concrete entity, to create a graphic object for another, and to graphically represent a narrative. Thus, children could fulfill their intentions through either medium.

Theoretical Implications

The findings of this study are consistent with the suggestion of Harste, Burke, and Woodward (1982) that print information is not clearly differentiated from other communicative systems (e.g., mathematical, artistic, dramatic). Harste et al. stress children's use of these systems to communicate a message; whereas, based on my observations, I stress children's use of primarily pictures, letters, and numbers to resemble or symbolize a meaningful aspect of their environment, which aspect could simply be a particular alphabet letter which the child knows well (see discussion of Figure (a).[1]

This concept of writing to symbolize a concrete entity as the one most widely evidenced in this classroom; the children could "write" objects pictorially or with letters, conveying the referent's full meaning through talk. The children's writing behaviors, including their talk about their writing, suggested that young writers may initially view print as direct graphic symbolism, rather than as a representation of speech, which in turn stands for referents. That inference is based on this study which aimed to examine children's writing and drawing from the vantage point of their own understandings and intentions, their own structuring of the writing and drawing tasks. That hypothesis must be verified through the use of researcher-structured tasks and the examining of greater numbers of children across age levels. Nonetheless, when combined with the theoretical and research literature on writing development, this study's data offer support, found in the spontaneous activity of children, for Vygotsky's (1978) theoretical position. That is, the documented close association of writing with drawing may represent an important developmental transition from, as Vygotsky suggested, drawing things to drawing disembedded language. For in order to write, children's transparent tool, language, must become an object of reflection (Vygotsky, 1962). In a sense, that's what the observed children were doing; they were making the names of particular objects (like Damon's *church* and Tracy's *Sonya*) graphic, visible, objects of reflection.

In this regard MacKay and Thompson (1968) have observed that young English children, writing by using word cards, progressed from simply listing words with no apparent link, to writing telegraphic sentences, such as "Mary ball," which are read as complete sentences, "Mary has a ball," (behavior consistent with Ferreiro's 1978, 1980 work) and then finally to writing a complete sentence. The names of people and objects were made visible, concrete, and then the transfer to writing as language ("visible language") was made.

Theoretically, then, this study's findings imply that the process of learning to write is, in part, a process of differentiating and consolidating the separate meanings of two forms of graphic symbolism, drawing and writing, as children encounter them and make use of them in their daily activities. The findings suggest as well that the essential discursive nature of the writing process--its connection with language--is not obvious to young children. Contrary to popular belief, writing may not begin as speech written down. The differentiation of writing from drawing and its precise connection with language is not necessarily a step preceding, but a gradual process occurring during and through first attempts to represent experience through letter graphics.

In our efforts to understand the development of written language we need to search for such interrelationships between children's use of alternate symbolic modes and for changes in those interrelationships over time. A consideration of writing development, including writing which occurs before children are functioning within the conventional alphabetic writing system, should be included within such research efforts to understand the growth of early symbolization as those described by Gardner and Wolf (1979, p. ix): studies of early symbolism across a variety of modes which "should yield a picture of symbolic competence which takes into account growth within individual media, relations among media, sources of symbolization in other domains of growth, and the possibility of diverse routes to symbolic competence."

Teaching Implications

The findings of this study have implications for practice as well. The school's goal of helping children learn to write is a deceptively simply description of an inherently complex phenomenon. To connect with the views of children themselves, particularly those who are just beginning their own exploration of this "writing" phenomenon, we might do well to, first of all, place increased value on children's own spontaneous exploration of the writing process (including such elementary acts as asking how one spells "my mommy's name"). In addition we might also consider the range of contexts for writing presented in school. Children need opportunities to identify the diverse range of situations in which writing and/or drawing are the chosen modes of expression in our culture (cf. Florio & Clark, 1982). As children dictate comments about their drawings, receive and respond to letters through the classroom mailbox, produce homemade books for the classroom library, make presents and cards for parents and peers, and similar tasks, they are actively involved with expressing ideas in global and discursive forms, learning the respective rules of each.

In closing, I share here five-year-old Courtney's perception of the drawing/writing relationship. It was near Christmas, and Courtney, like many of her peers, was into drawing Christmas pictures. While drawing Santa one day, Courtney remarked, "I would spell Santa Claus if I was six." I agree with Courtney. I have argued here that, from the children's perspective, the transition may not be from speech to writing, but from drawing to writing, and then the connection with language is made. The vivid images, memories, and dreams which surround Courtney's drawn Santa will one day, I hope, be transformed into elaborate drawings and extended prose as she grows in the ability to symbolize her experiences for herself and for others.

I am indebted to Celia Genishi for her thoughtful comments on earlier drafts of this paper.

1. The difference in stress between the Harste et al. paper and my own is perhaps attributable to the research setting. The children in the former study were writing in interview situations for an adult, whereas the children in the current study wrote spontaneously because they "wanted to."

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The Visibility of Colored Characters on Colored Backgrounds in Viewdata Displays

Margaret Bruce and Jeremy J. Foster

An experiment is reported in which subjects were required to identify letters and digits presented on a viewdata display, and identification times were recorded. All 42 possible color-on-color combinations were shown as separate displays. The results indicate which color-on-color pairings significantly reduce character visibility, and a list of recommended combinations is given.

Viewdata is one of the most significant developments in mass communications of recent years. It consists of a system in which the user's television is connected to a central computer via a telephone link. The computer has a store of thousands of pages of information which the user can have displayed on his television screen by entering the appropriate page numbers on a key pad. The system differs from broadcast teletext in the number of pages available, the greater control that the user has over what information he can access, and in the ability of the user to communicate to the central computer. Viewdata systems are in operation in a number of countries, the first public system having been initiated in the UK by the British Post Office (now British Telecom).

Viewdata provides information in the form of verbal and numerical displays, but the facility for transmitting pictures is becoming available. A notable contrast with printed alphanumeric displays is the ease with which color can be used. With a color television receiver the characters can be in any of seven alternative colors: white, yellow, cyan, green, magenta, red, blue. Each individual character can be displayed on a background of any of the other colors. (Characters are drawn within a 6 x 10 matix, and those cells of the matrix which are not part of the character form the background of that character.) There are, therefore, a total of 42 different color/color combinations available, and the color of characters and backgrounds can be varied individually within a line.

This facility compensates, to some extent, for the spatial limitations of the TV screen. It has no practical counterpart in print. The relative luminosity of a colored character is likely to be more degraded by a colored background in print than in CRT mode, and so it is unlikely that studies of the visibility of colored print (e.g., Konz et al., 1972) can be applied directly to viewdata. Experiments on the visibility of projected slides may be more relevant to CRT displays. Snowberg (1973), for example, varied

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background color and measured readers' visual acuity using a snellen-type chart. However, the lettering was black and this has no equivalent in viewdata. Nevertheless, it is worth noting that he recommends a white background, which maximises the contrast between the characters and the ground.

The newness of the medium has meant that little information has been published concerning the visibility and legibility of viewdata displays. This situation has been commented upon by various authorities (e.g., Reynolds, Spencer, and Glaze, 1978; Sutherland, 1980) who have also debated whether the design principles known to be appropriate for printed material are also applicable to viewdata's CRT displays. The dissimilar physical characteristics of ink-on-paper and CRTs have led some commentators to argue that it is unwise to generalize across the media (e.g., Hurlburt, 1980). In his discussion of Prestel, Sutherland (1980) observes that there have been no studies on the visibility of colored characters on colored backgrounds. The present experiment was designed as an initial contribution to this topic.

METHOD

Respondents were asked to identify aloud alphanumeric characters displayed in lines on a viewdata screen. The character color and the background color of the displays were varied. The experiment consisted of a mixed design, with background color (B) being a within-subjects factor and character color (C) a between-subjects factor.

Stimulus displays

There are 42 possible color/color combinations, and therefore 42 displays were prepared. Each consisted of lines of characters, the first three containing three full upper-case alphabets in random order and the fourth containing each of the digits 0-9 three times, the sequence again being random. A viewdata screen includes 24 lines of 40 character spaces. The top and bottom lines are reserved for information concerning the frame being viewed and routing instructions, so there are 22 lines available for the frame content. In the present displays the top line of characters occupied the centre line and the other three lines were below this one, with a blank line between each line of characters. All the spaces not occupied by characters were filled with the same color as formed the background for the characters, so that the screen contained a large colored rectangle with the lines of characters extending downward from the centre.

Six different character sequences were created, and each was produced in every one of the seven possible character colors. The background colors were allocated so that every possible color-on-color combination was available, and each character color was used once with every character sequence, but with a different background color each time. Background colors were allocated randomly to the particular combinations of character sequence and character color.

Subjects

There were seven groups of eight respondents, who were students from various undergraduate courses and were assigned randomly to the character color groups. None of the subjects had had any prior experience with viewdata. The subjects in any one group saw six displays, all having the same character color but a different background color and a different sequence of characters. The order in which background colors were displayed was determined randomly and separately for each respondent.

Procedure

Subjects were run individually. Trials were run in a cubicle 3 x 3 metre with an ambient illumination from overhead light-bulbs of 50 lux. The subject sat 1.5m from the screen of a 16″ ITT Teletext receiver (Model TVX). The surface between the reader and the television screen was matt black, and care was taken to prevent any reflections in the screen. The displays had previously been recorded on audio cassettes, and could therefore be "written" on the screen at will. The experimenter sat 1.5m to the subject's right, and manipulated two tape-recorders, one of which wrote the display while the other was used to record responses. She also manipulated a black screen which was interposed between the subject and the receiver while displays were being changed.

The respondents were asked to identify out loud all the characters. The time taken for each of the four lines was measured later from the tape recordings of the responses. Uncorrected errors were negligible, and insufficient for statistical analysis.

Results

Every respondent yielded sets of data for 6 color/color combinations. For each of these the data from the 3 lines of letters was averaged to give a measure of the mean time taken to identify each letter, and similarly a mean time taken to identify each digit was calculated. These recognition times, expressed as 1/100sec, form the dependent variable.

Because of the necessary absence of any data for those cases where a colored character would be superimposed on a background of the same color, it was not possible to apply analysis of variance to the total set of data. Instead, the experiment can be seen as seven within-subjects experiments, each of which involved the manipulation of background colour while character colour was constant. A separate analysis of variance was applied to each sub-experiment, which manipulated two factors: background colour and character type (letter or digit). Since digits were always the final row of the displays, character type is confounded with presentation order, and any effects of character type must be interpreted with caution.

In none of the analyses was there a significant interaction between background color and character type, and consequently in Table I we show the mean recognition time per character for each character color (merging the data for letters and digits). Background colors were compared using Duncan's Multiple Range Test, and the outcomes are shown in the penultimate column of Table I. Background colors which share an underline do not differ from one another at the $p<.05$ level. The results for each character color will be considered separately.

White characters There was a highly significant background (B) effect ($p<.00001$), but character type (T) and the B x T interaction were non-significant. Using Duncan's Test, white-on-yellow characters were harder to identify than any of the other combinations, which did not differ significantly.

Yellow characters Background was significant ($p<.005$), but T and B x T were not. Cyan and white backgrounds were significantly worse than the others; blue, red and magenta formed the group yielding the fastest scores.

Cyan characters Again, background was the only significant factor ($p<.002$). Green and yellow backgrounds yielded the slowest performance; blue, white and red were the best grounds.

Green characters Background was significant ($p<.04$), and so was character type ($p<.03$) but the interaction was not. Digits were identified faster than letters, but as mentioned above, this factor was confounded with presentation order and so should be interpreted cautiously. The most visible backgrounds were, in rank order: yellow, white, red, magenta, and blue.

Magenta characters Background was the only significant factor ($p<.00001$). Red was the worst background color; blue, white, cyan, and green produced the most visible magenta characters.

Red characters Both background ($p<.002$) and character type ($p<.001$) were significant factors, but the interaction was not. Digits were identified faster than letters. The magenta ground was significantly less visible than the others, which did not differ between themselves.

Blue characters Neither of the main effects (background or character type) was significant, nor was the interaction. Despite the non-significant background effect, Duncan's test indicated that red and magenta grounds were worse than white, which was the best ground for blue characters.

DISCUSSION

So far as we are aware, Table I provides the first set of published data on the visibility of colored viewdata characters seen against colored backgrounds. It therefore serves as the first empirically-devised guide for designers wishing to discover which color combinations reduce character visibility.

It is, however, necessary to consider the limitations of the data tabulated here. These limitations derive from the displays, the viewing environment, the subjects, and the task which the subjects were asked to perform. There are three aspects of the displays upon which we feel comment is required. First, the characters were in unbroken lines, with one blank line between successive lines of characters. It is possible that where significant effects were observed here, they would cease to be significant with more generous inter-item spacing. We feel it unlikely, however, that increased inter-item space would produce alterations in the *relative* visibility of color-on-color combinations where significant differences have been observed here. (For example, we would expect magenta to remain the worst background for red characters). Second, the "empty" areas of the screen were filled with the background color, and it is possible that this affected the magnitude of the effects observed, although we again doubt whether it is likely to have influenced the relative visibilities of the various color combinations. Thirdly, only upper-case letters were used, which means that we cannot be sure that the results apply to lower-case.

The environment in which our respondents viewed the displays had an ambient illumination lower than that recommended by Ostberg (1975, cited in Sutherland, 1980). With a higher level of ambient illumination, the contrast between the colors will be less pronounced, although contrast can be adjusted to some extent by the control on the television set. We expect that those combinations in which the contrast between character and ground is low and which tend to have poor visibility would be even less visible with high ambient illumination. But the precise interactions between ambient illumination and the visibility of color-on-color displays have yet to be determined.

Another aspect of the viewing environment is the particular television set. Sutherland (1980, p.23) writes: "Studies of the legibility of text and of viewer's color preferences on Prestel are bedevilled by the fact that the appearance of characters in a given color varies with the manufacturer of

Table I Mean recognition time per character (1/100 sec) as a function of character color and background color, and the outcome of Duncan's Multiple Range Test to compare background colors.

Character Color	*Background color* W	Y	C	G	M	R	B	*Duncan's MR Test*	*Relative Luminances*
White	—	47.85	39.46	37.72	36.50	37.51	37.85	MRGBCY	BRMGCY
Yellow	50.47	—	48.22	43.50	43.07	41.97	40.35	BRMGCW	BRMGCW
Cyan	38.57	44.43	—	44.20	41.20	39.11	36.86	BWRMGY	BRMWYG
Green	36.74	36.66	40.98	—	39.85	39.41	39.89	YWRMBC	BRMWYC
Magenta	40.07	44.07	41.03	42.97	—	52.38	39.91	BWCGYR	BWYCRG
Red	33.49	34.79	35.36	35.75	41.47	—	36.00	WYCGBM	BWYCGM
Blue	38.01	39.06	40.25	40.89	41.77	41.22	—	WYCGRM	WYCGMR

the set, the age of the set and the ambient lighting conditions. On some sets white is a very bright color, on others it appears a rather dirty grey; as sets age, the beams illuminating the different phosphors may get out of alignment, and colors produced by more than one phosphor may yield blurred edges; morever, the phosphors deteriorate with use . . . " These considerations need to be borne in mind when the results of any experimental studies of viewdata visibility are being evaluated or applied.

The subjects used here were not screened for visual defects, but none reported when questioned that they suffered from color blindness. They were in the age-range of 18-30 years, and it is likely that elderly people, or those with visual defects, would experience greater difficulties when reading viewdata. People with specific types of color blindness can be expected to find some combinations particularly difficult. It remains to be seen whether the relative visibilities of the color pairings differ for particular groups of readers.

In the present study readers were asked to identify the characters orally, since this ensured that they had indeed identified all the characters displayed. Although this procedure has its drawbacks, we doubt whether it is likely to have biassed the comparisons between the displays. But it may not be wise to generalize the present findings to different tasks, such as those involving visual search. The present findings should not be applied without reservation to the design of text displays; direct studies of the effect of color on text legibility are required.

Table II Recommendations for color-on-color combinations for viewdata displays.

With characters of this color . . .	*avoid this color of background . . .*	*use one of these*
White	Yellow	Magenta Red Green Blue
Yellow	White Cyan	Blue (Red) (Magenta)
Cyan	Green Yellow	Blue (White) (Red)
Green	Cyan Blue	Yellow White (Red) (Magenta)
Magenta	Red	Blue White (Cyan) (Green)
Red	Magenta	White Yellow Cyan Green
Blue		White (Yellow) (Cyan) (Green)

Bearing all these qualifications in mind, it is possible to derive from Table I a set of recommendations about which backgrounds to use or to avoid for each character color, and we have done this in Table II. Creating such a set of recommendations involves a certain amount of subjective judgment, since there are no objective rules for deciding where to locate the criteria of acceptance and rejection. The "reject" column of Table II includes those backgrounds which fall in the "least-visible" grouping of each row of Table I. In the "recommended" column of Table II we have entered those background colors which are in the "most visible" grouping of each row of Table I. We have inserted a maximum of 4 background colors in this column. Where the "recommended" colors also featured in the second-most-visible grouping of Table I, we have put brackets to indicate that they possess a less clear-cut advantage.

It is not possible to use Table I to compare the visibility of character colors in isolation: to do this, characters should be displayed on an uncolored background. The results of experiments employing such a procedure are summarized in Sutherland's (1980) report.

Reynolds et al. (1978) state that the theoretical relative luminances of the various colors are: white 100, yellow 89, cyan 70, green 59, magenta 41, red 30, blue 11. It therefore seems worth considering how far the results shown in Table I are related to the relative luminances of the various hues. As an index of relative luminance, we calculated (c-b)/b where c represents the luminance of the characters, and b the luminance of the background. This provides an index of relative luminance, which can be used to predict the visibility of the color-on-color combinations. The final column of Table I lists the background colors in decreasing order of the magnitude of the luminance index, for each character color. These orderings can be compared with the orders of visibility shown in the adjacent column of Table I.

The most notable differences between the two orderings are for red characters, where a blue ground is predicted rank 1 but observed rank 5; for white characters where blue is predicted rank 1 but observed rank 4; and for green characters where blue is predicted 1 and yellow predicted 5 while the observed values are the reverse. The rank correlations between the two orderings of background colors for each character color are: white +0.60, yellow +1.0, cyan +0.77, green -0.09, magenta +0.71, red +0.43, blue +0.94. With the notable exception of green, these suggest that relative luminance is one factor influencing character visibility. Furthermore, the *range* of luminance indices is much lower for blue than for any other color, and this may be compared with the fact that it was only with blue characters that the analysis of variance failed to demonstrate a significant effect of background color. Also, when the relative luminance index falls below 0.3, the resulting combination is always in the least-visible grouping for that character color. (The converse does not hold: there are least-visible pairings such as magenta on red where the index is above 0.3, in this instance 0.37). As a rule of thumb, one can say that to promote character visibility one should ensure that the relative luminance index does not fall below 0.3. It would not, however, be correct to recommend maximizing the index since this would involve always using blue as one of the pair of colors. The data shown in Table I simply do not support such a strategy.

In more everyday terms, the analysis indicates (1) that a "light" color should not be paired with another "light" color ("light" colors being white, yellow, and cyan), (2) that the "dark" colors (red and blue) should be paired with a light one and (3) that the "medium" colors (green and magenta) should be paired with colors from one of the other groups. These rules are in broad agreement with Table II.

Finally, a further note of caution: the displays used here contained only a single character color and a single background color. It is quite easy to create displays with both colors varying across the whole range so that one can have a frame containing up to 42 separate color/color combinations. Intuitively one expects there to be a danger of creating a form of visual indigestion by the excessive use of color variations. How color/color combinations should themselves be combined (if at all) remains to be investigated.

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The Woolly Jumper: Typographic Problems of Concurrency in Information Display

T. R. G. Green and S. J. Payne

The well-documented use of typographical cues to illuminate instructional text has in the past been limited to illustrating *containment* relations (sections within chapters or subsections within sections) and *succession* relations (after one chapter we come to the next). No other relations have been studied. Powerful though containment and succession are, other relations also exist, and in particular the rise of information technology will make it increasingly necessary to document the relation of concurrency. As it happens, descriptions of simple concurrent processes are already found in knitting patterns, so our suggestions for typographic expression of concurrency are worked out on a fragment of knitting to give a domestic and readily-grasped example.

There is plenty of evidence that well-designed typography improves the quality of instructional texts. Hartley (1978) cites studies showing that both comprehension and recall can be significantly improved by redesigned layouts, utilizing spatial cues and typographical cues to bring out the sense. Figure 1 shows an example of Hartley's suggestions: he argues that the structure of text can be displayed to a reader by varying in proportion the amount of vertical space between units in the text. In highly technical text new sentences start on fresh lines, or are even separated by a line-space (as in Figure 1). In less technical text, paragraphs are separated by one line, sections by two, chapters by four. The endings of lines should coincide as far as possible with syntactic boundaries, rather than coming haphazardly at any point in the syntactic structure and sometimes even breaking up words which then have to be hyphenated. In Hartley's "vertical spacing" scheme, horizontal spacing is not used unless the structure of the document has so many levels that the vertical separations become excessive.

As Hartley himself points out, this is only one scheme among several which have the same aim of displaying structure for the reader's help. Frase and Schwartz (1979) carry the approach much farther, using different levels of "meaningful indentation" to display different levels in the hierarchy of phrase and clause. As Figure 2 shows, the result is very different from Hartley's.

Each system has pros and cons — for instance, "meaningful indentation" works well enough on a single page, but page turns make for

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ASSIGNMENT PROCEDURES

Conventional assignment procedures are applied when subscriber service is assigned to a spare physical circuit that is providing a working derived circuit. Additional information related to the derived line is entered in the remarks section of the service order (Figure 3.9). Rearrangement of the cable pairs that include pairs used for single channel carrier circuits should be avoided where possible. Such arrangements require coordination among the engineer of outside plant, assignment office, central office, outside work forces, and repair service bureau to ensure that transmission requirements are met. Also, bridge tap restrictions for single channel carrier application may not permit cable pairs to be half-tapped in the central office and/or field location, and may prohibit use of carrier once the outside plant facilities are reconfigured.

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Also, bridge tap restrictions for single channel
carrier application may not permit cable pairs to be
half-tapped in the central office and/or field location,
and may prohibit use of carrier once the outside plant
facilities are reconfigured.

Figure 1. Top, a passage of technical material in original layout. Bottom, the same passage spaced according to the procedures of Hartley (1978) and Burnhill (1970). The passage comes from Frase & Schwartz (1979).

```
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```

Figure 2. The same passage as in Figure 1, laid out using the "meaningful indentation" procedure (from Frase & Schwartz 1979).

problems when many indentation levels are used. Is the first line of the new page seven deep or only six?

Despite the difference in approach, both examples start from the same rationale: that learning, comprehending, and recalling prose all involve the segmentation of text into meaningful groups, and that the groupings can be made clearer to the reader by spatial means. Normally printed text, in contrast, does not make these groups readily apparent, and the problem is particularly acute with technical materials. This rationale is very convincing. The purpose of the present paper is not to quibble with it, but to ask whether we can extend it.

Relations and Representations

The schemes illustrated above are different ways to map the relations of *containment* and *succession* into spatial layout. In Hartley's scheme, chapters contain sections, sections contain paragraphs, paragraphs contain sentences. These units are separated by vertical space, indicating the level of containment. Within each level, objects occur in succession — chapter 1 is followed by chapter 2, etc. The Frase and Schwartz scheme maps the same relations, containment and succession, in a different way. In their scheme the objects are much lower-level, phrases and clauses rather than chapters and paragraphs, and the spatial cues are different: containment relations are shown by indenting, and succession is shown by vertical spacing.

Containment and succession are very powerful relations, and many types of structure can be summarized with no additional concepts. A still more general concept can be obtained by adding trivial extensions to indicate elements that can be repeated or can be omitted. This allows us to describe the structure of not just one book, but any book. For instance, *The King's English* (Fowler & Fowler, 1906) is a book consisting of a head and a body, with a preface and a contents list contained in the head. The body contains two parts, with four chapters in the first part, and so on. This gives us the following structure:

The King's English:
  HEAD:
    preface
    contents list
  BODY:
    part 1:
      chapter 1
      chapter 2
      chapter 3
      chapter 4   etc.

But the generalized book can also be defined, and it would look somewhat like this:

BOOK:
  HEAD:
    PREFACE (optional)
    INTRODUCTION (optional)
    CONTENTS LIST (optional)
  BODY:
    PART: (repeatable)
      CHAPTER (repeatable)
  TAIL:
    INDEX (optional)

This is not truly a description of the generalized book, containing no reference to different volumes, possible appendices, new prefaces to later editions, etc.; but it will describe a very large number of textbooks.

This style of presentation can be regarded as a grammar. It states that a book is a head followed by a body followed by a tail. A head may contain any or all of preface, introduction, and contents list. A body contains at least one part, maybe several, each containing at least one chapter. A tail may contain an index. So the sequences:

Preface — Part 1: Chapter 1 to 3: Chapters 4 to 7 — Index

Introduction — Contents List — Part 1: Chapters 1 to 10

would be "legal sentences" of the "language." Our textbook grammar is an example of a *context-free-phrase-structure grammar*, whose mathematical properties are now well understood (Gross and Lentin, 1970). Many other systems can be described in the same way, such as school algebra. For algebra we choose to represent succession and containment using brackets rather than indenting; but we could equally well write:

(x + 1) / ([x + 2] × 3)

as

```
x + 1
            /
x + 2
        ×
3
```

Equally well from a logical point of view, that is. From a psychological viewpoint it is very doubtful that the two versions would be equivalent.

The rationale proposed by Hartley and others can now be rephrased in rather more grandiose terms as follows. Instructional texts can be described as context-free phrase-structure grammars, as can many other structures. Mapping the relationships within the grammar into spatial layout will display the structure more clearly to the reader, and will make the text easier to comprehend, learn, and recall. The choice of a particular mapping (such as Hartley's or Frase and Schwartz's) may prove better or worse for readers but it does not alter the fundamental logic of the system.

Concurrency

Our contention is that although the rationale is excellent as far as it goes, it needs to be extended. Some textual material, as we shall demonstrate, cannot be represented as a phrase-structure, so the argument falls over the first hurdle. The material we have in mind is that which is required to illuminate two or more *concurrent* processes — processes which are executed at the same time.

Sometimes concurrent processes are actually carried out simultaneously, but most of the time this is a clever illusion created by scheduling and interleaving. When a team of chefs prepare a dinner, each one preparing one part of the meal independently, the processing is parallel; but when one cook prepares all the dishes, moving swiftly from pot to pan, the processing is concurrent but not truly parallel.

In many circumstances concurrent processes can be presented with little strain on the notation — users can be left to work out the concur-rency relation for themselves. In a cookery book, for example, each recipe instructs the cook to perform a sequence of steps in the order given. However, the cook prepares a meal by interleaving a number of recipes, arranging matters so that all processes for the main course terminate at approximately the same instant and the potatoes do not have to wait too long for the sausages. In doing so the cook neatly models the scheduler in a computer system, keeping track of the various concurrent processes, turning to one when it needs attention and then to another. At some point all these semi-independent processes meet in a "rendezvous" (a term now taken into the fold of technicality with its use in the programming language Ada; see Pyle, 1981). At the rendezvous point each process waits for the others until all have reached it, and the meal is then ready. During preparation there may be other rendezvous points, for instance the sauce may be ready before the fish, and it is put aside until the fish is ready too.

It is no accident that our introduction to concurrency has borrowed terminology from computer science. We expect that the problems of displaying concurrency in instructional texts will become increasingly common, primarily due to the actions of computers. As the information technology revolution spreads silicon into home and office, the problems of documenting and understanding continually more intelligent devices will tax the resources of technical writers. The complexity of digital watches, for example, is already impressive; and some models with "dual time," "chronograph," and "lap time" features already perform several types of timekeeping simultaneously. A modified finite state diagram of one such device is shown in Figure 3. Clearly the advanced features of the device, including concurrent processing, force complexity into the descriptive notation.

The Woolly Jumper

One type of technical material already contains descriptions of concurrent processes as a matter of routine: the knitting pattern. The authors have collected anecdotal evidence which suggests that knitting patterns are not as clear as they could be. Some knitters, for example, require the pat-

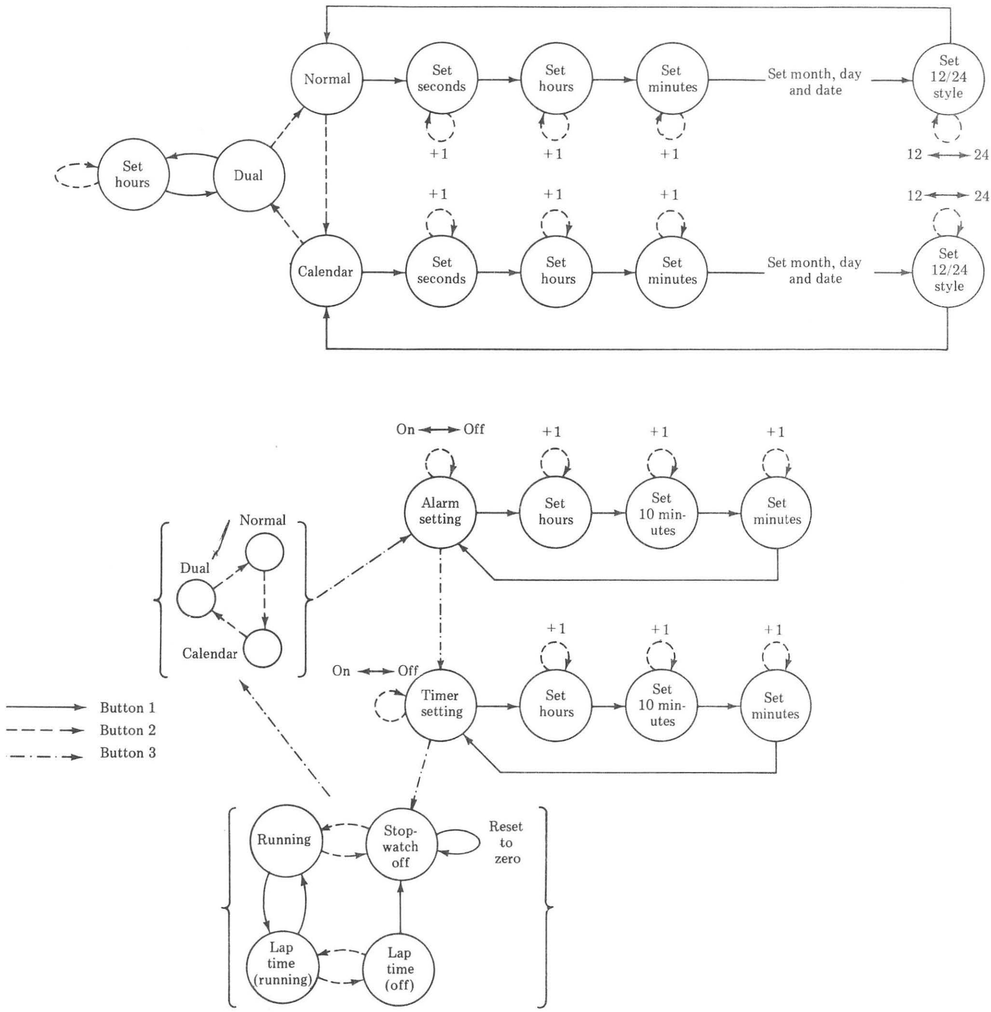

Figure 3. The increasing complexity of digital watches already gives problems. In this diagram the conventional state-transition notation would make it necessary to draw many more states; instead, a new convention has been introduced that braces mean "any of." Thus braces round the (duplicate) trio of dual, normal, and calendar states mean that button 3 will lead from any of those into the alarm-setting state; and button 3 will also lead from any of the four stopwatch states in braces back to whichever of dual, normal, or calendar states was earlier in force (from Green, 1982).

terns to be translated into an audio-notation: one lady described the joys of reading aloud (stitch by stitch) to grandmother; a second championed the use of a tape recorder. None of the experts we talked to boasted an understanding of knitting patterns sufficient to develop some picture of a garment from its pattern; yet an equivalent task is performed regularly by experts in other domains, musicians for example. Finally, none of our knitters could recover from small mistakes by making a corresponding adjustment elsewhere in the garment. Knitters, it seems, habitually unpick to the point where the error was made. As a foretaste of the problems, let us try decomposing a fragment or two, isolating the relations of containment, succession, and concurrency.

At present, knitting patterns are usually printed in a highly abbreviated style. Some publishers make use of typographical and spatial cues, while others restrict themselves to a uniform typeface and a spatially compact layout, giving the reader very little assistance in discerning the segmentation. Figure 4 is a fairly typical example. Here we have a structure which has several levels, not all of which are evident at first glance to untutored eyes. (Indeed, the entire notation of knitting may be obscure at first sight, and the authors thank the native speakers who acted as their informants). In Figure 5 the principles of "meaningful indentation" have been applied to segment the structure into its containment and succession relationships.

BACK. Cast on 65 (69-73-77) sts. and work in rib.
1st row. - right side K.2, * p.1,k.1; rep. from * to last st., k.1.
2nd row. K.1, * p.1,k.1; rep. from * to end. Rep. these 2 rows twice more. Now work in patt. with rib borders as follows:
1st row. K.2, p.1,k.1,p.1, k. to last 5 sts., p.1, k.1, p.1, k.2.
2nd row. [K.1,p.1] twice, k.1, p. to last 5 sts., [k.1,p.1] twice, k.1.
3rd row. Rib 5, * k.2 tog.; rep. from * to last 4 sts., k.1, p.1, k.2.
4th row. [K.1,p.1] twice, k.1, * k.loop, k.1; rep. from * to last 4 sts., rib 4. These 4 rows form one patt. Cont. in patt. without shaping until work measures approx. 63 (63-64-64) cm. from beg., ending with a 4th patt. row.

Figure 4. Fragment of a knitting pattern. Abbreviations: k = knit, p = purl, st. = stitch, sts. = stitches, patt. = pattern, rep. = repeat, tog. = together. The asterisk is used to delimit the scope of a repetition instruction (from pattern 7328, booklet 244, 3 Suisses, 1980).

The sheer size of a knitting pattern presented in the style of Figure 5 should make us pause; but a considerable reduction could be made by putting some instructions on the same line, even though that is against the spirit of the indentation principle. In any case, this is a problem which will be more extreme with knitting, with its very terse commands, than in other technical material. Otherwise, however, this is a very successful exercise, and the structure of the original pattern has very readily allowed itself to be recast in a different form.

Now consider this fragment:

> Now decrease 1 stitch at armhole edge on next 4 rows, then decrease 1 stitch at same edge on the next 5 alternate rows, but at the same time decrease 1 stitch at front edge of next row and every following 4th row until 11 decreases have been completed at front edge, after which decrease 1 stitch at front edge on every 3rd row until 36 stitches remain.

The most obvious point is that two processes are to proceed concurrently, the shaping of the armhole and the shaping of the neck. The scheduler (who is in this case the knitter, of course) must interleave them satisfactorily. As so often happens in plain English, Ambiguity makes an appearance: where does the phrase "at the same time" start operating, at the beginning, "Now decrease . . .," or at the phrase "then decrease . . ."? Probably the latter.

```
BACK:
Cast on (differing numbers
        of stitches for
        different sizes
Edge: (do 3 times)
  1:
    k. 2
    repeat until last st.:
      p. 1
      k. 1
    k. 1
  2:
    k. 1
    repeat to end:
      p. 1
      k. 1

Pattern: (repeat until
          work measures
          enough cms.)
  1:
    k. 2
    p. 1
    k. 1
    p. 1
    repeat to last 5 sts.:
      k.
    p. 1
    k. 1
    p. 1
    k. 2

  2:
    do twice:
      k. 1
      p. 1
    k. 1
    repeat to last 5 sts.:
      p.
    do twice:
      k. 1
      p. 1
    k. 1
  3:
  .............
```

Figure 5. Part of the pattern in Figure 3 presented using "meaningful indentation."

(Main part of pattern)

....

....

FORK

ARMHOLE	NECK
4 times:	4 times:
decrease 1 row	don't decrease
———— *rendezvous* ————	
5 times:	11 times:
decrease 1	decrease 1
don't decrease	3 times:
until rendezvous:	don't decrease
don't decrease	until 36 stitches left:
	decrease 1
	do 2 times:
	don't decrease
———— *rendezvous* ————	

JOIN

....

....

(Rest of pattern)

Figure 6. One approach to the presentation of concurrent processes.

What aids to the reader can we muster?

One possibility that we do *not* want to consider is writing out all the decreasings in full. Not only would that use a lot of paper, but also it would destroy the designer's achievement of separating the two processes, which is part of the segmentation we want to display. The effect would be like this:

> Now decrease 1 stitch at armhole edge on next 4 rows, then decrease on both edges on next row. Don't decrease on either edge on the next row, then decrease on armhole edge alone on the next row. Don't decrease on either edge on next row (and so on).

Although this might look bearable with an effort, even a slight increase in the complexity of the processes to be interleaved would make it totally obscure. It would become virtually impossible to separate one process from the other.

Figure 6 shows another possibility. In this arrangement we have separated the two processes, "armhole" and "neck," showing where they fork and join. Each process has been presented using the conventions of "meaningful indentation," because they feel better here, but any other conventions could equally well be used. It is not possible to maintain a precise horizontal alignment, row for row, of the two processes because they have differing control structures; but we have marked two alignment points with a "rendezvous" cue. This is meant to help the user perceive some of the temporal structure relating the concurrent processes, and to check on their relative progress. Thus our notation not only displays *concurrency* but also displays *synchronicity* where appropriate.

Alignment points can also be used as part of the control structure. The first rendezvous point in Figure 5 is present so that the user can check that both processes have reached the required stage. The second rendezvous point is part of the control structure, being used by the armhole process for the instruction "keep idling until the other process has reached the rendezvous, and then go on with the next instruction."

The evidence cited by Hartley (1980) shows that the various forms of spatial cues to structure have empirically demonstrable results. There are now a large number of studies reported dealing with various possibilities and their effects. But this literature deals exclusively with the relations of containment and succession; there is no corresponding body dealing with the notation of concurrency.

The closet approach is the consideration of conventional musical notation (Sloboda, 1981). In parallel score arrangements two or more concurrent processes are presented (e.g., the left-hand and right-hand parts of piano

Figure 7. From a keyboard manuscript. London, 1540 (from Sloboda, 1981).

music). The music is arranged so that correspondences in time are matched by correspondences in space, and Sloboda describes the layout as "orthochronic." Even experienced performers still benefit from cues to synchronization, such as vertical alignment of bar lines in the separate parts. (cf. Figure 7 showing a splendid manuscript, c.1540, written before standard bar lines were introduced).

It would be particularly useful to collect evidence on the cueing of concurrency. In doing so the usual measures should, of course, be taken in the usual tasks, such as those of comprehension, learning, and recall, mentioned above; but it is clearly desirable to shape some of the experimental tasks explicity towards the problem of concurrent processes. What will the state of process A be when process B does such and such? Can their actions be scheduled successfully, either by executing them "for real" or else in the head? Can it be seen whether one process reaches a particular point before the other process reaches some other point? In the case of knitting, problems also arise about modifying the processes; if one side has gone wrong in a specified way, can the knitter see how to modify the other side? For instance, suppose the back shaping came out a row too short, is it possible to subtract one row from the operation of the front shaping without disaster, or must the back be unpicked?

In our suggestion for the representation of concurrency we have chosen to show only the fork and the rendezvous. Is this sufficient? Maybe empirical tests against genuine tasks will reveal that more must be shown, such as the transmission of information from one process to another when it takes place; or perhaps the particular representation we have chosen will be shown to be inadequate. We would like to see improvements to our suggestion, and we would like to see them empirically tested; and — however important the woolly jumper may be to the British way of life — we would particularly like to see tests against fullsize technical material, rather than isolated fragments of knitting patterns.

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COMPUTERS, WORDS & ARTS

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