GRAPHICAL CONVERSATION THEORY

COMPUTER MEDIATED INTER- AND INTRA-PERSONAL COMMUNICATION

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ABSTRACT

The following pages outline a five-year program of research into the application of artificial intelligence techniques to interactive systems, emphasizing computer graphics. The unifying theme is that of a "graphical conversation theory," a formal interpretation of discursive communication including the widest variety of modes and media, simultaneously enriching and transparent.

There exists little precedent for a strictly graphical conversation. At best, in lieu of graphical dialogue, we find graphical monologues augmenting utterances. Moreover, we perceive computer graphics to be in a conservative state, weighed down by its line-based origins, confined by small windows into large worlds, and derailed by the difficulties of graphical input. The spirit of this proposal is to burst out of this recalcitrant shell into languages of sounds, gestures, shape, and color orchestrated by the user with objectives to satisfy the varying demands of engineering, education, office automation, artistic expression, and home recreation.

The proposal introduces paradigms for interaction and mediation, conversing with one's self and conversing with others. These are elaborations culled from verbal conversation theories and from experience with highly interactive computer graphics. These are followed by an array of tasks and landmarks that progress from terminal-like activities to room-like surrounds, implementing such fantasies as sound-sync drawing with one's eyes.

The proposal results from and is the continuation of momentum gained over six years of NSF support in computer-aided design, augmented by industrial and other federal sponsorship, extensively reported in the Appendices.

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helped write this proposal. The text was produced during a soul-searching and sleepless month.

Cover designed by Louis Weitzman and produced at the Visible Language Workshop

1.0 INTRODUCTION

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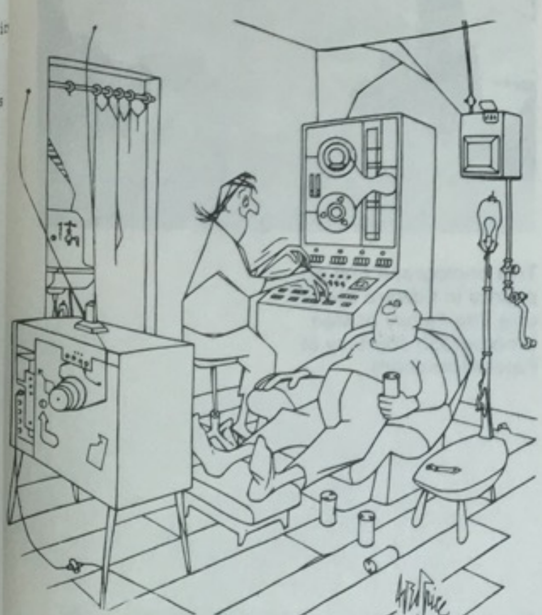
The proposal is noticeably long. This is because we are trying to establish a theoretical foundation, to report on a history of experiments, and to propose an agenda of new research. Recent encounters, publications, and symposia lead us to the conclusion that very little attention is being devoted to interaction in the deepest sense of the word. We genuinely believe that computer science is in desperate need of richer interfaces with people. This is especially true in a time when we can foresee plummeting costs and skyrocketing power, hand in hand.

Two levels of argument are intermixed throughout this section and the entire proposal. At one level, we can liken the present situation in computing to the hand calculator market where costs have dropped and capabilities have risen to the point that the manufacturer is forced to look at the interface to find a competitive edge (feel of the keys, luminance of the numbers, importance of hard copy, and the like). The consumer devotes relatively little time establishing the level of mathematical sophistication required and spends a great deal of time testing to see "if it feels good." We are implying that the hamburger jingle "have it your way" might be mapped into a growing population of powerful, personal computers. To evaluate the interface on the basis of "I like it" is not a disheveled scholarly approach, but is, we argue, the epitome of creative computing.

Another level of postulate surrounds the differences and similarities between interpersonal and intrapersonal conversation. In both cases the computer makes possible the achievement of certain kinds of understandings. Additionally, the conversation has justification for its own sake, namely, traveling is as rewarding as getting there. In short, we introduce this volume with the philosophical stance that computers can offer the



(Cartoon from January 13, 1968, issue of Business Week. Courtesy of George Price) highest form of personalization and be the richest amplifiers of creativity, though currently they are not.

The first Chapter of the proposal introduces the concept of "graphical conversation theory." What is a graphical conversation? Why is it important? And how do you know when you have had one? We interweave these questions with explanations of the characteristics of a graphical conversation, the notion of an intelligent system, and the specifics of computer architectures.

The following two Chapters bisect the problem into interaction and mediation. They have been written quite purposively avoiding specific reference to techniques for interaction in order to leave open the definition of hardware and to stay free from the present-day realities of what a machine can and cannot do. In most instances examples are drawn from human-to-human discourse or from personal experiences that are widely shared.

Chapters 4.0, 5.0, and 6.0 compose our five-year scenario of approaches, projects, and tests. They are heavy on techniques and attitudes, and judicious in the application of formal testing in the genre of experimental psychology. In some cases we have gone out on a limb, postulating display and input technologies that some people might argue will not be available even five years from now.

Chapters 7.0, 8.0, and 9.0 are "boilerplate." They have been printed on gray stock, and divide the three-hundred pages of appendices from the main text. The gray sections are included to convince the reader that some of our fancies are not so fanciful, that we are at the leading edges of various relevant technologies, and that we will stay there. A large measure of our position is based on convincing the reader that we have the kind of industrial support that will bring to our attention technologies that

This photograph first appeared in Edward Steichen's *The Family of Man*. (Photograph courtesy of Peter Moeschlin)

might otherwise take two or three years to permeate into the field.

The last of these gray pages is the proposed budget, the total of which is strikingly high because of the five-year duration. We feel strongly about this level of continuity in order to pursue what we believe to be a very complicated problem for which research time is more important than research size. On a year-to-year basis, the budget, measured in constant dollars, is lower than our current NSF funding. In part this is because we have extracted a large applications component of our current effort. But in greater part this is because we expect to continue to attract concurrent research which is both more mission-oriented and applicable to our results.

Finally the reader is confronted with the appendices, which are preprints or recent reprints, germane to this proposal. There is a large number because of the a-contextual nature of many of our propositions. We allude to the appendices in every section in order to provide exemplars or evidence that might otherwise be lacking. It is important to add that, during the three years of our current grant, two books have emerged: *Soft Architecture Machines* (MIT Press, 1975) and *Computer Aids to Design and Architecture* (Petrocelli/Charter, 1975). With the exception of Appendix I, a reprint of Dr. Gordon Pask's introduction to *Soft Architecture Machines*, the contents of these volumes have been subsumed in the following text.

A final note on style. This proposal has been written by nine people who include:

an experimental psychologist
a computer scientist of graphics upbringing
an operating systems expert
a hardware specialist
a cybernetician
an actor
an architect
a color theorist
a technical voyeur

Only marginal attention has been paid to undoing stylistic differences.

1.1 Where Words Fail

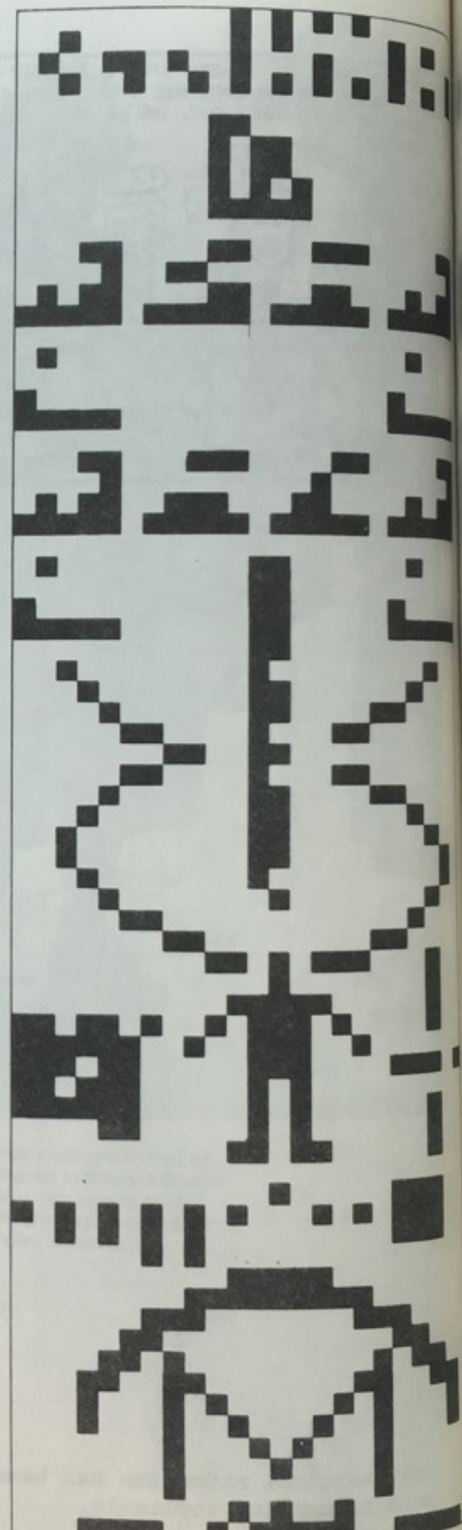
In some quarters the venerable maxim "a picture is worth a thousand words" is undergoing careful scrutiny.

Recently there has been a flurry of activity among psychologists toward the end of contrasting experimentally the relative efficacy of words versus pictures with respect to, for example, the memorization and recall of information and the utility of verbal encoding versus imagery in cognitive tasks generally. Indeed, one recent article has been entitled "Some of the thousand words a picture is worth," suggesting that the current exchange rate may be as determinable as that for changing francs into marks, or lira into dollars.

However, there is little dispute that the question is an important one, for it impinges upon the deeper question of how any of us gains information about the world (perception), how we process that information (learning; memory; cognitive processing), and how we communicate with others (linguistics; communication theory). One cannot help but wonder, accordingly, whether or not there is some deep sense in which words and pictures are profoundly different as modalities.

The noted philosopher and theoretician of art, Susanne K. Langer, has essayed this question in her seminal book *Philosophy in a New Key*. Words, she maintains, are preeminently discursive in nature; that is, verbal symbolism, indeed all language as such, has a form that demands that ideas expressed in it be disclosed linearly and sequentially, even ideas that are inherently all-of-a-piece. An important consequence of this is that ideas that do not lend themselves to this peculiar ordering become ineffable, or inexpressable, through words.

This property, however, does not entail the notion that only linguistic, discursive forms of thought have order and rationale:



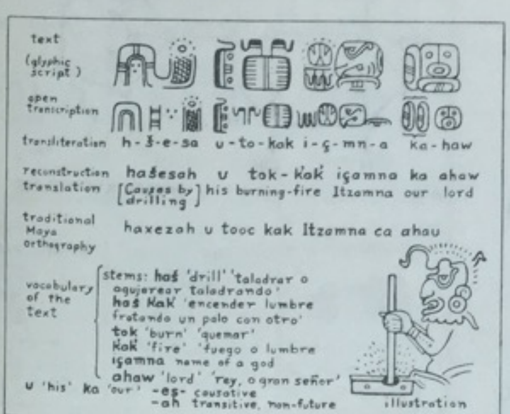
Langer, Susanne K., "Philosophy in a new key", Cambridge, Mass.: Harvard University Press, (1960)

> *Visual forms -- lines, colors, proportions, etc. -- are just as capable of __articulation,__ i.e., of complex combination, as words. But the laws that govern this sort of articulation are altogether different from the laws of syntax that govern language. The most radical difference is that __visual forms are not discursive.__ They do not present their constituents successively, but simultaneously, so the relations determining a visual structure are grasped in one act of vision. Their complexity, consequently, is not limited, as the complexity of discourse is limited, by what the mind can retain from the beginning of an apperceptive act to the end of it ...* [Langer, p. 93; emphasis in original]

The possibilities afforded by the visual, the __presentational__, are not without qualification. Professor Langer continues:

> *... Of course such a restriction on discourse sets bounds to the complexity of speakable ideas. An idea that contains too many minute yet closely related parts, too many relations within relations, cannot be "projected" into discursive form; it is too subtle for speech ...* [Langer, p. 93; emphasis in original]

The symbolism afforded by the apprehension of forms nonetheless provides a valid realm for the projection of ideas that defy linguistic portrayal. On the other hand, realization of the extent to which the human nervous system can "make sense" of kaleidoscopic color arrays (or of sounds, noises, tactile sensations) and render them as "things" has wrongly encouraged the notion that there is a "language of the senses," or a "language of form," and so on. Langer avers that __true language has essential features that are__ missing in the presentational sphere. First, every true language has a vocabulary and syntax. The elements are __words__, and their meanings are fixed. Second, word equivalencies are established; it is possible to define words, that is, to construct a __dictionary__. Last, different words may be used to convey the same meaning, specifically, __translation__ is possible (Langer, p. 93-94).



Analysis of a Maya sentence taken from page 38 of the Codex Tro Cortesianus.

In contrast, these features are profoundly lacking in nondiscursive symbolism. In a picture, for example, the elements are not units with independent meanings, but are patches of light and shade. Consider a photograph:

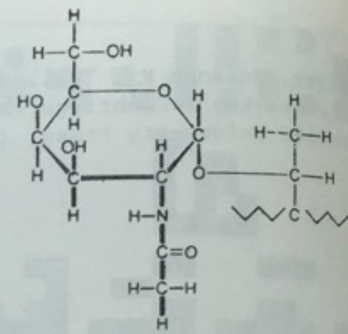
> ...[*The gradation of light and shade*] *cannot be correlated, one by one, with parts or characteristics by means of which we might describe the person who posed for the portrait. The "elements" that the camera represents are not the "elements" that language represents. They are a thousand times more numerous. For this reason the correspondence between a word-picture and a visible object can never be as close as that between the object and its photograph ... . That is why we use a photograph rather than a description on a passport or in a Rogues' Gallery.* [Langer, p. 95; emphasis in original]

The ability of a picture or photograph to render a one-to-one or element-by-element correspondence with its subject, as elaborated by Langer, is referred to by Rudolf Arnheim in his book, *Visual thinking,* as "isomorphism":

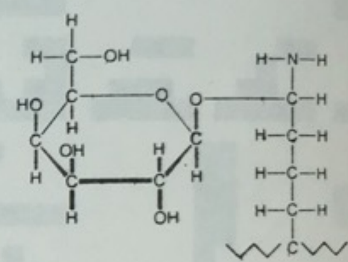
> *The principle virtue of the visual medium is that of representing shapes in two-dimensional and three-dimensional space, as compared to the one-dimensional sequence of verbal language. This polydimensional space not only yields good thought models of physical objects or events, it also represents isomorphically the dimensions needed for theoretical reasoning.* [p. 232]

But Arnheim seems also to be saying that the visual representational mode is suitable for "theoretical reasoning" as well as representing shapes. This contrasts with Langer's theme that visual forms, being nondiscursive, are not consonant with theoretical reasoning insofar as this way of thinking is linear and sequential in nature.

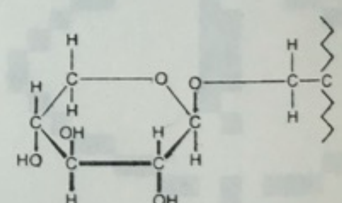
Langer's philosophical agenda in *Philosophy in a New Key* was to plead the case that the realm of pure form had an inherent "logic" of its own, that this "logic" was not that



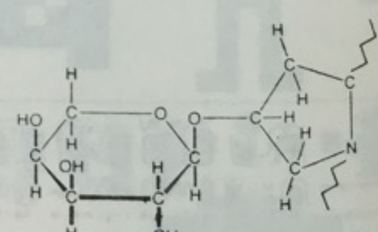
GalNAc THREONINE



Gal HYDROXYLYSINE



Xyl SERINE



Ara HYDROXYPROLINE

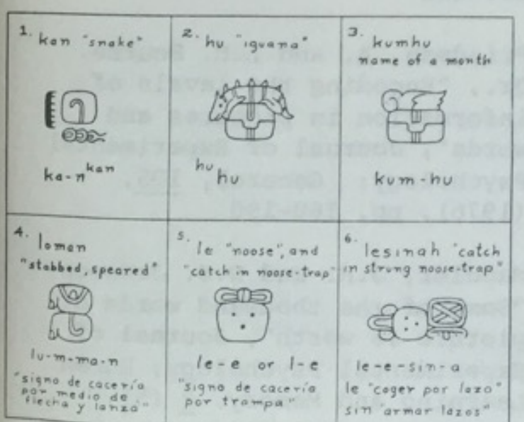
Langer, Susanne K., "Philosophy in a new key", Cambridge, Mass.: Harvard University Press, (1960)

of linear, discursive thought, but rather was attuned to the sentient, the intuitive. Music, for example, was an analogue of emotion. Langer's intent was not to play off these intellectual and affective modalities one against the other and then to argue that one was somehow better in an absolute sense than the other, but rather to contrast them so that the potentialities of either mode were appreciated in terms of each one's own sphere of action.

Arnheim, in comparing and contrasting the linear and verbal with the simultaneous and visual, invokes the notion that representation in discourse need not be restricted entirely to one mode or the other; the relevant issue is that of the ratio of one mode to the other along the dimension of isomorphism with the referent:

> *All media of representation can rely on isomorphic and on non-isomorphic references. They are partly analogues, partly signs. In principle, there is no difference in this respect between verbal and non-verbal languages. The most important difference in practice is one of ratio. In the visual area or in music, for example, strictly non-isomorphic references are exceedingly rare. In verbal language, they do the most work. A continuous gamut of shapes leads from the least to the most isomorphic media; it includes such intermediate features as onomatopoetic speech sounds, ideographs, allegories and other conventional symbols. To put verbal language in a class of its own is misleading.*
> [Arnheim, p. 251]

Arnheim, R., "Visual thinking", Berkeley and Los Angeles, Calif.: University of California Press, (1969)



Maya sign clusters representing words.

In its isomorphic aspect, the visual medium (read "graphical") is, for Arnheim, "...so enormously superior [to words] because it offers strucural equivalents to all characteristics of objects, events, relations" (Arnheim, p. 231). The utility of language in enabling thinking cannot be that of thinking in words as such, but in the ability of words to make available to thinking more appropriate media such as visual imagery. Concepts, which may be referred to by words and propositions, are, for Arnheim, "perceptual images";

the operations of thought are precisely the handling of these images.

It is evident from the expositions of such thinkers as Langer and Arnheim that not to have a proper concern for the graphical component of discourse is to falsify discourse; this component cannot be selectively ignored or passed over, because it interacts intimately with the verbal, discursive, and primarily non-isomorphic component.

Our focus of concern is on discourse, conversation if you will, through and with computers, involving one or more human users. Our emphasis in this proposal is on the graphical component, broadly conceived, of such discourse, and our intent is to explore and elaborate the implications of this component for man-computer dialogue. Central to such an effort is a formal, comprehensive theory of conversation.

Pylyshyn, Z., "What the mind's eye tells the mind's brain", Psychological Bulletin, 80, (1973), pp. 1-23

Hannay, A., "Mental images: a defense", New York: Humanities Press, Inc., (1971)

Paivio, A. and I. Begg, "Pictures and words in visual search", Memory and Cognition, 3, (1974), pp. 515-521

Potter, M.C. and B.A. Faulconer, "Time to understand pictures and words", Nature, 253, (1975), pp. 437-438

Friedman, A. and L.E. Bourne, Jr., "Encoding the levels of information in pictures and words", Journal of Experimental Psychology: General, 105, (1976), pp. 169-190

Mandler, J.M. and N.S. Johnson, "Some of the thousand words a picture is worth", Journal of Experimental Psychology; Human Learning and Memory, 2 (5), (1976), pp. 529-540

1.2 Conversation Theory

A conversation is a series of understandings between participants. These words are used in the technical sense developed (as a conversation theory) in connection with work on human learning, decision, and design, where the tasks to be done, and/or the knowledge to be gained, are large enough to count, as realistic rather than "laboratory sized." As a rule, such situations involve several participants and are handled, in practice, by the liberal deployment of machine augmentation and by the encouragement of man-machine interplay (which is not to be confused with man-machine conversation; as it stands, participants engage in dialogue with each other, not with machines or computer-implemented aids, however intelligent these may be).

The largest present application of conversation theory is to educational and cognitive psychology; hence, the ideas and methods are readily illustrated in this field of research. Further, the salient results are most easily highlighted by comparing and contrasting findings in this area with those of other methods currently in use.

For example, classical behaviorism (stimulus response theory) adopts the input/output situation as basic and, with it, the paradigm in which measurements are made at an interface between the organism and its environment. The measurements/observations in question are surely objective (i.e., it referenced); however, difficulties crop up when the organism is a human being; not the least of which is that phenomena involving consciousness are, by definition of the paradigm, excluded from theoretical consideration. This consciousness appears as an epiphenomenon or, at best, a correlate of brain activities and processes.

The difficulties are far less obtrusive if the basic unit of observation and measurement is taken to be a series of transactions (henceforward a conversation, if the conditions to be stipulated are satisfied) that form part of a dialogue between participants in a conventional language and that refer to a domain of topics or behaviors.

Ample precendent for this point of view is furnished by the work of Piaget, Luria, and Vygotsky; who have used "question-probing interviews" or "paired experiments" in their investigations. Typically, the subject and the experimenter (or, in the context of education, the student and the teacher) are both regarded as participants in the dialogue. Their catalytic role (provocateur to information source or mentor to student) is well specified, but their systemic/organizational boundaries are not, because the dialogue, which is deliberately encouraged by this technique, exteriorizes normally private cognitive and conative operations as stretches of utterance in the conversational language. The utterances in question are said by this theory to image concepts in the participants' mental repertoire. Concepts are regarded throughout as executable, mental procedures rather than, for example, as stored patterns. Insofar as the technique is successful, one participant literally reprograms (shares mental procedures with) the other, and vice versa. The core of the dialogue is a series of agreements between the participants in which one agrees to an explanation. This topic or event is pointed out by the other (using an implicit or explicit "how" question to evoke the explanatory reply. Further, the participant agrees to a derivation, or account of how this correct explanation was offered, rather than an indefinitely large number of other correct explanations/derivations, of precisely the same topic, all of which might have been offered. Such agreements (explanations and derivations together) are known as understandings. On theoretical grounds it can be argued that understandings reflect a process whereby a class of executable procedures (concept) has become stabilized by the prior existence or acquisition of other procedures that are capable of

IN THEIR COUNTRY HOME NEAR BRISTOL, THESE PARENTS HAVE TWO CHILDREN: ONE IS ELECTRONIC.

Vivian Dovey and Grey Walter have two offspring: Timothy, a human baby and Elsie, the tortoise, of coils and electronic valves. Timothy is very friendly with his mechanised sister.

reconstructing members of this class from concepts for other topics in the domain.

With this background in mind, we return to the beginning of this subsection and define a conversation as a series of understandings between participants in the context of a domain, which consists of a representation of what may be known and done.

There is an outstanding problem: How does one recognize understandings and insure that they take place? (The dialogue does not, for example, degenerate into haphazard repartee.) If the conversational language is a natural language (as tacitly assumed until this juncture), then the problems are commonly acknowledged and are chiefly bound up with the facile and unambiguous interpretation of natural language expressions. To avoid these difficulties, mechanical-symbolic languages have been employed as surrogates in order that verbal explanations/derivations can be replaced by nonverbal explanations/derivations, the validity of which may be sensed by suitable algorithms. Something of this kind was done, without recourse to a theoretical framework, by other researchers. For example, Piagetian interviews often refer to a collection of objects or puzzles, and as a closely fitting example, the programming language LOGO is used to build models (interpretable programs) that, upon execution in the computer and its peripherals (Turtles, Music Boxes) realize the topic under discussion. It is essential to make a distinction between the behavior of a model (interpreted program) when it is executed by the computer and the behavior involved in creating and correcting the model (program). Only the latter behavior counts as a nonverbally-exteriorized explanation, representing the existence of a concept, though it is true that human beings are able to behave otherwise. For example, a human being may execute the concept that the exteriorized program represents and act out as an unqualified behavior, the motions of a Turtle or its homologue.

More than this is needed to vouch, nonverbally, for the stability of reconstructibility of a concept if that concept is exteriorized nonverbally. There must, at least, be some other modeling facility, akin to the LOGO computer but tied, in this case, to the knowlege representation of a conversational domain. The participants are thus able to model their derivation(s) of concept(s) from their own preexisting concepts for other topics, which also belong to the conversational domain. Such nonverbal derivations are called "learning strategies" and "teaching strategies" in the referenced literature and are usually displayed visually, to both participants, by means of state markers distributed over a replica of the knowledge representation, which we call entailment meshes (see subsection 1.5.2).

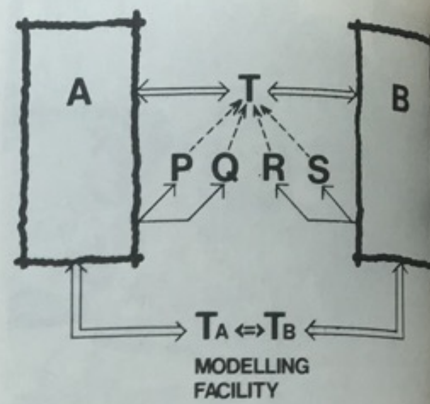


Figure 1

Thus, to exteriorize a conversation, the participants (shown as A and B in Figure 1) build up and agree about models that will, if correctly executed, realize topics (such as topic T in Figure 1). They are also required to build up and agree about at least one, and possibly many, models for the derivation of topic T (for instance, in Figure 1, participant A reconstructs topic T from topics P and Q while participant B reconstructs topic T from topics R and S). Notice, also, that A's explanatory model for T (representing A's concept of T) need not be identical with B's explanatory model for T (representing B's concept for T). It is only required that A and B are in agreement that execution of these models "does the same thing" (the equivalence or " —— " sign in Figure 1), that is, that an interpreted relation called topic "T" which is currently ostended (pointed at) is realized and satisfied.

Figure 2 reconciles these linguistic notions with a special variety of behaviorism -- a many-sorted behaviorism, characteristic of conversation theory (the stretches of explanatory and derivational behavior that represent understandings). These many-sorted behaviors are suggested by the labels in Figure 2, though, in general, as many kinds of behavior are

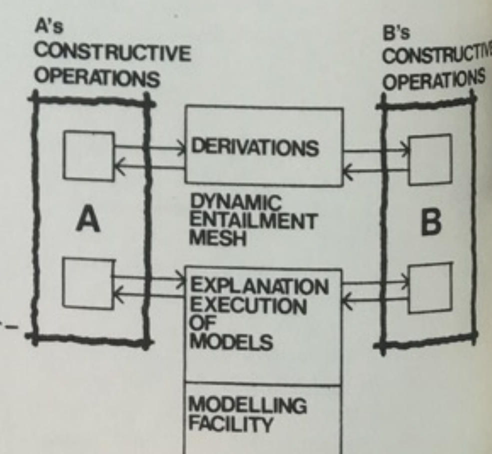


Figure 2

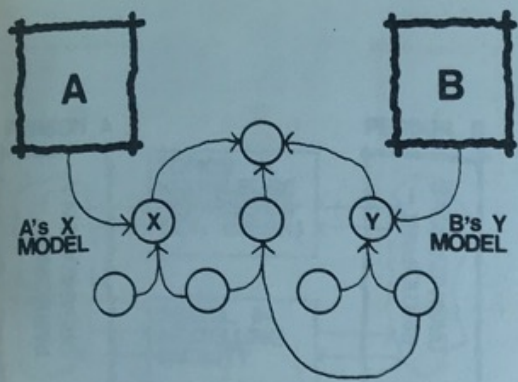


Figure 3

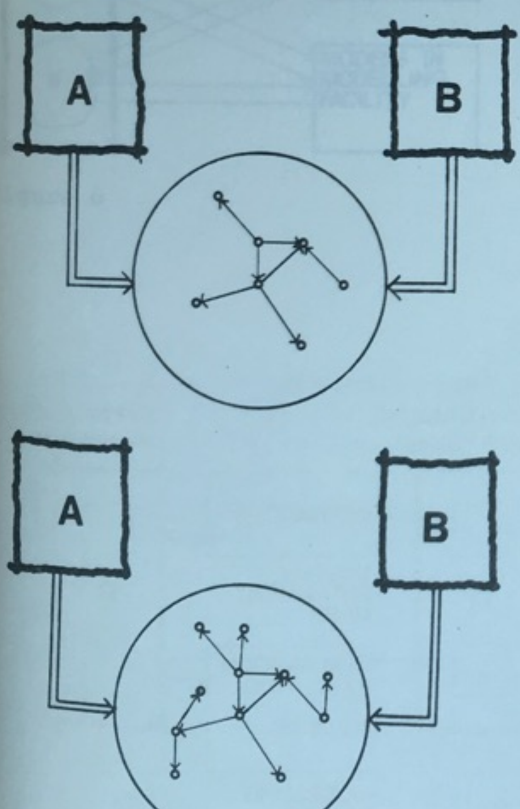


Figure 4

distinguished as may, under given conditions, be needed to express the fact of understanding. The most readily implemented conversation is known as a strict conversation. Checking heuristics are used, to guarantee that all topics said to be agreed are, in fact, understood; the most economical type of heuristic incidentally ordains that topics are understood in a linear sequence (S before T, for example, or vice versa). This kind of regulatory heuristic imposes a restriction upon the representation of knowledge as it is displayed, namely, that, although the participants deal with different topics (perhaps simultaneously), they restrict their focus of attention to one "perspective" or "point of view" (in the referenced literature, an "entailment mesh" becomes an "entailment structure"). Roughly speaking, this constraint implies that the knowledge representation of the conversation domain is distorted from a fundamentally cyclic organization into a union of trees, as it would be if seen from a particular perspective. Strict conversations have served to delineate, for example, species of learning strategy and teaching strategy. But the strict conversational paradigm has been rightly criticized as far too limiting and, consequently, unrealistic.

In more recent studies it has been possible to relax the strict conversational restrictions (1) by allowing participants to adopt any chosen perspective (and to generate "entailment structures" locally from an underlying "entailment mesh" [Figure 3] -- an expedient essential for experimenting with innovation), and (2) by allowing the participants to act in the role of theorists or subject matter experts (Figure 4) who modify and enlarge the knowledge representation of the conversational domain.

Even laboratory realizations of these liberalized conversational paradigms (understandings that occur in a series that is not linearly sequenced) call for extremely flexible interface media; for example, for simultaneous presentation of several potentially independent working models. Serious applications in design, management, and other fields contemplated in this proposal are thus known, from prior experience, to call for dynamic graphic media and, in order to make sense of the transactions permitted, a graphical conversation theory that is a substantial improvement on and extrapolation of the existing theoretical structure.

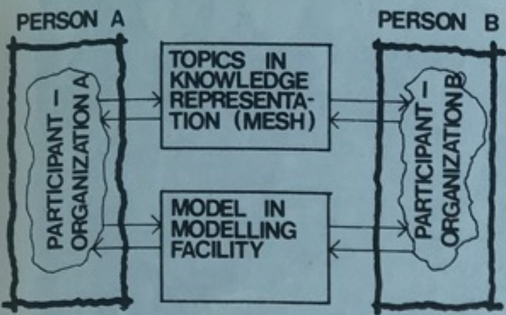


Figure 5

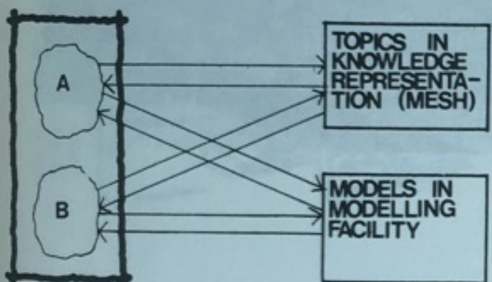


Figure 6

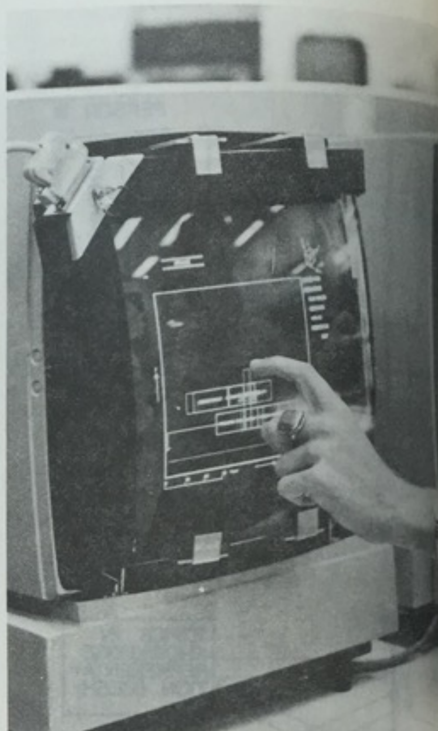
1.3 Interpersonal Versus Intrapersonal Dialogue

Participants A and B were deliberately left unspecified during the previous section, except that A and B constituted organizationally or systematically discrete and integral entities.

Any conversation relies upon participants who converse. But the power of conversation theory would be severely restricted if the theory could only accomodate interpersonal conversations; that is, conversations in which A and B are identified as different people (as shown in Figure 5). In fact, people do learn on their own, people do direct their own attention, and people do act as isolated inventors. These possibilities are encompassed by the theory sketched in Figure 6 where A and B are identified with distinct organizations coexisting in the same brain.

As a result of this construction, "learning on one's own" is rephrased as "teaching oneself" and implies the postulation of distinct mental organizations (A acting in the same capacity of teacher and B in the capacity of learner). Along the same lines, the next phrase "directing one's own attention" is supposed to designate a construction in which "A directs B's attention and B directs A's," where A and B engage in an "internal conversation." To rephrase the last example (creativity, innovation, invention) involves rather more than this since there is evidence that, under these circumstances, A and B may (perhaps momentarily) exist independently, becoming dependent if, and only if, the conversation brings about an agreement between the participants.

All of these "internal dialogues" are legitimate examples of intrapersonal (rather than interpersonal) conversation. Hence, it is reasonable to ask, "How much of the internal dialogue is externalized or exteriorized for observation and measurement?" The answer to the question must remain, "As much as possible." But the inquiry is far from novel. Interpersonal conversation (A and B are two separate persons) is equally open to question. Interpersonal conversation depends upon a contract between A and B and the experimenter to the effect that A and B will converse. Failing that, A and B cannot be forced to converse (as an organism might be forced, by starvation, for example, to behave in pursuit of reward). In much the same manner, intrapersonal conversation depends upon a contract to establish and to maintain a conversation between organizations or systems in the same brain (namely, organizations A and B) that are to that extent regarded as integral entities whose dialogue may be behaviorally exteriorized. This contract, essential in either case, is imaged, theoretically, as the conversation itself and is intimately connected, if not identical, with A's consciousness of B and B's consciousness of A.



1.4 Characteristics of Graphical Conversation

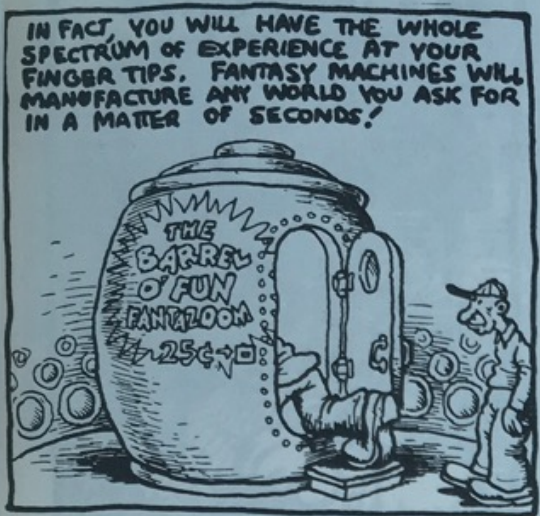
To draw, to scribble, to doodle, and to "jot down" are graphical acts with which we are familiar on a day-to-day basis. Rarely does the medium draw, scribble or doodle back at you; "jot up", so to speak. In short, that dynamism of graphics is not a commonplace occurance, and it is precisely that dynamism that turns drawing from a static memory medium into an interactive processing medium.

The following eleven subsections presuppose graphics to include a universe of volatile discourse, and not just lines. The term "graphics" can be read as "nonverbal", inclusive of dimensions of sound, color, 3-D projection, and entire surrounds of multiple media (see Appendix III). In other words, the graphical conversation is not justified by the line-work of projective geometry or diagramming, but by the concatenation of shapes, colors, sounds and systems of force feedback. Similarly, graphical input is not just a tablet or a light-pen, but fingers, gestures and body movement.

It is critical to engage in speculation at this point, leaving evaluation until Chapter 2. Our user is not sitting in front of an Imlac engaged in graphical retort. Instead he is in a milieu of his own design, with ambient information strewn in three-space. Each wall is a display, his fingertips emit color, his desk is virtual, and landmarks of sound guide data from the periphery to the fovea of his attention. The environment is built upon redundancy.

Garner, W.R., "Attention: the processing of multiple sources of information", in "Handbook of perception", E.C. Carterette and M. Friedman (eds.), New York: Academic Press, 2, (1974)

Is such a vision a route to sensory overland and saturation, a computing circus, or, worse, a road to a seonc-rate psychedelic nightclub? Our premise is built around "no" from two perspectives. One, by redundancy (Garner, 1974), be it across media or modes, we do not imply gratuitous information but expansions of "field of vision." Two, by multiplicity, be it of sensory inputs or instruments of control, we mean a user invoked and designed system, namely, a very personalized and sensitive medium akin to an excellent butler (section 3.2, Appendices II and IV).



1.4.1 Liberality

The computer is the most liberal of all available media. Its nature is limited only by our imagination and our capacity to interact with it. It can do more than merely describe a system. It is a dynamic medium. It allows a human being to affect and be affected by machine operations so that the interaction is with a system rather than, as so often imagined, with a Turing representable machine.

Computer programs are able to simulate "worlds." For example, FORTRAN programs, data retrieval systems, and physical, economic and social systems. The system the user perceives need not appear to obey the usual principles of computer science, let alone the restrictions and restraints of the physical universe.

With the addition of graphical interaction, a considerably wider range of simulations becomes possible. No longer restricted to the one-dimensional nature of the typewriter terminal, the user can interact with the medium in a much more natural way. Space and time, and thus motion, are perceived directly, not as interpolations of numbers typed on a console. Moreover, the immediacy of graphics permits an enhanced perception of causality (Michotte, 1946).

Michotte, A., "La perception de la causalite", Louvain, (1946)

These principles have been employed in a wide range of computer-aided design (CAD) systems. Two dimensional automated drafting systems (such as Computervision's Applicon's or Gerber's) simulate a rough approximation of pencil and paper. The user enters lines by graphically specifying endpoints, storing overlayed drawings in "layers," and starting a new sheet by erasing the screen. Press-on or rubber-stamped figures are implemented by graphical sub-pictures. Some other CAD systems simulate not only paper, but the object being designed as well. There are numerous systems for design of electrical circuits that simulate the operation of the circuit. The KINSYN system developed at MIT allows a user to describe a

Spragg, S.D.S., A. Fink and S. Smith, "Performance on a two-dimensional following tracking task with a miniature stick control, as a function of control-display movement relationship", Journal of Psychology, 48, (1959), pp. 247-254

Kaufman, R. and A. Rubel, "KINSYN: a minicomputer-based interactive mechanism design system", Proceedings of the 13th Design Automation Conference, (1976) mechanical linkage which he can then operate, observing its motion on a dynamic display.

The essentially parallel nature of human visual perception can be used to advantage in the presentation of parallel processes. Through the many degrees of freedom offered by the computer medium, independent universes can be simulated. The worlds created in this manner need not obey the familiar couplings of space and time, but can behave in arbitrary manners, with arbitrary concepts of causality, and hence the liberality. Through graphics, a user can examine several of these worlds simultaneously, determining their interrelationships. The comparison may be between a plan and a section of an architectural design, or might be of a chemical reaction viewed from two different frames of reference. The analogies formed as a result of this operation are contended to be an essential aspect of innovation. (See subsection 1.4.9, Series Not Sequence.)

The liberality afforded by the computer graphics will have profound implications for our concepts of art and literature. Unlike much of contemporary technology, which provides pale imitations of previously existing media, the computer makes possible a whole new range of expression and communication. Rather than just reading a book, it will be possible to return to the period about which it was written, or to hold a conversation with the author.

1.4.2 Transparency of the Interface

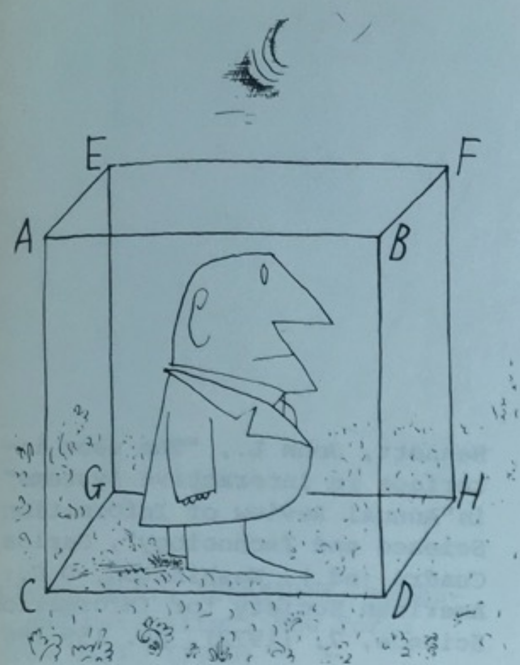
As stated in the previous subsection, the computer is capable of creating arbitrary universes or worlds of action and execution. To render such a world useful, the interface given the user must be sufficiently unobtrusive to allow him to think and act in terms of that world. The experience should be one of talking <u>through</u> a computer. Individual actions lose their intrinsic value and are thought of only in terms of their effect, in much the same way as a person becomes unconscious of phonemes when speaking.

There are many factors that determine the transparency of a given interface. The user must be able to infer an association between cause and effect and internalize that inference to the extent that it becomes unconscious. This process is easier if the two are in harmony. For tasks that involve spatial relationships, this requirement indicates a graphical means of input and output. Tasks involving time similarly require dynamic displays. Imagine driving a car with two buttons labeled Turn Left and Turn Right. Even worse, imagine having to type those same words at a keyboard.

A given choice of interface may not be correct for all people. While human beings are very adaptable, and good systems design often takes advantage of this adaptability, different levels of detail may be required for different people performing the <u>same</u> task. Returning to the automobile example for a moment, there are two common control systems. The automatic transmission was invented to provide simple, two-pedal control over the speed of the vehicle, providing a reasonably transparent interface that has become the choice of the majority of Americans. Many people, however, find that the automatic transmission does not provide enough subtle control, and are willing to internalize the somewhat more complicated structure of the "standard" transmission. The choice has implications for both user satisfaction and economy.

Although the standard is theoretically capable of smaller fuel consumption, an unskilled driver may burn more fuel with an improperly operated standard transmission than with an automatic.

In graphics systems, there are, of course, many factors that would bring benefits to all users, such as improvement of the resolution and viewing comfort of computer displays. Although the goal of a transparent interface is furthered by removing or rendering unobtrusive any constraint irrelevant to the dialogue in progress, care must be exercised that the user is not offered an unduly restricted set of possibilities. This will require a knowledge of the set of possible needs in a graphical conversation and an understanding of how the choice of techniques affects those needs.



1.4.3 Transparency of the Medium

The last subsection described how the man-machine interface may be made transparent by rendering it unobtrusive. Details not relevant to the task at hand are handled automatically. This subsection uses the term "transparency" in a slightly different way, to describe an approach to the medium by which the medium can be so well understood that it can be used without requiring a great deal of new knowledge to be introduced whenever a new facet of it is explored. This can be best achieved if the same techniques for interacting with the medium are also used to describe it.

A major problem in the design of good user interfaces has involved the necessity to trade off simplicity and power. A simple-to-use system often cannot perform many of the tasks performed by a complex system. There is widespread agreement that the set of available functions must be consistent and predictable. The best approach to this problem has been to choose the basic concepts carefully so that a large body of knowledge can be remembered in the form of a simple set of axioms.

One way in which this can be done in a computer system is by eliminating unnecessary distinctions, one of the more troublesome being the distinction between programs and data. This allows the new user to apply information acquired on the manipulation of one to the manipulation of the other. This elimination of an arbitrary boundary has been used successfully in such systems as LISP, SMALLTALK, and TECO.

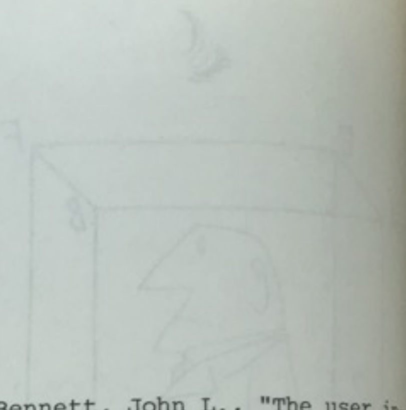
The introduction of graphics, with its attendant capacity to represent processes, offers a natural means of understanding and manipulating elements within the medium and the medium itself. One attempt at this was the SMALLTALK-based PYGMALION, which equated the manipulation of objects on the screen with the editing of a program.

McCarthy, John, et al., "LISP 1.5 programmers manual", Cambridge, Mass.: MIT Press, (1962)

Goldberg, Adele and Alan Kay (eds.), "SMALLTALK-72 instruction manual", Xerox PARC, March, (1976)

Smith, David C., "PYGMALION: a creative programming environment", Stanford Computer Science Dept., ARPA order no. 2494

By making the medium self-describing, its full power can be accessed by means of a number of simple concepts and the kind of transparency described in the last subsection. For example, if turning the steering wheel right turns the car right then turning it further should make the car turn more to the right. In this case of transparency the structure is unnoticed not because it is hidden but because it is so obvious.



Bennett, John L., "The user interface in interactive systems", in "Annual Review of Information Science and Technology", Carlos Cuadra (ed.), Washington, D.C.: American Society for Information Science, 7, (1972), pp. 159-196

Treu, Siegfried, "A framework of characteristics applicable to graphical user-computer interaction", ACM/SIGGRAPH Workshop on User-Oriented Design of Interactive Graphics Systems, Pittsburg, Pa., Oct. (1976)

1.4.4 Encouragement to Interact

"Space War" exemplifies the engaging quality of computer graphics. The player has a sense of delight and satisfaction, some aspects of which previously were available only through more destructive or dangerous means such as automobile racing, gun shooting, or smashing glass.

D. E. Berlyne coined the term "ludic behavior" from the Latin "ludere," to play. We wish to recognize two distinct views of the role of ludic behavior in the role of encouragement, though we side with the first. Berlyne writes,

> *...in human beings, ludic behavior includes everything that is classified as recreation, entertainment, or "idle curiosity," as well as art, philosophy, and pure (as distinguished from applied) science.*

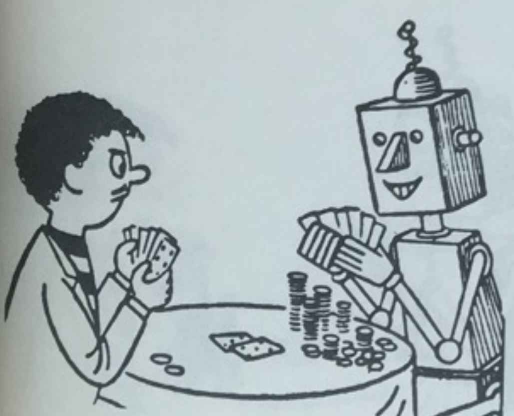
Berlyne, D.E., "Conflict, arousal, and curiosity", New York: McGraw Hill, (1960)

In contrast, in Drever's *Dictionary of Psychology* we find:

> *...activity, which may be physical or mental, existing apparently for its own sake, or having for the individual as its main aim the pleasure which the activity itself yields; usually involving also a detachment from serious aims and ends.*

Drever, James, "Dictionary of psychology", London: Penguin Books, (1962)

We hold that the "technology of fun" is not merely a recreational diversion but is a tool for problem-solving activities that should not be overlooked.



The other, more "respectable" encouragement to interact with a computer is that the machine provides a tool or facility for doing something not otherwise done as easily. Often this may imply providing means of exteriorizing a process not done well in one's head, such as arithmetic, storage and manipulation of large quantities of information, or visualization of three-dimensional forms. The benefit of such exteriorization accrues not only to the user of the system but to the experimentalist, who can make use of the information thus exposed to study the intrapersonal conversation that takes place. This technique is exploited in Chapter 6.0, Hypothesis Testing.

Given the dual motivations of fun and facility, what factors affect a person's willingness to interact with the machine? Ease and comfort of use are certainly important issues, especially for the new or computer-naive user. Transparency of the interface and transparency of the medium are crucial factors in making the power of the machine available for interaction. Finally, it is important that the user not face discouragement as he goes about his interaction with the machine.

The four factors of ease, comfort, transparency, and lack of discouragement have received much attention in the scientific community but are only beginning to assume an important role in the market place. To date, most computer applications have been in business and engineering, where the cost-saving of automation has been the determining factor. Many computer-aided design systems have poor human interfaces but find widespread use. Engineers will readily adapt to night-shift usage of an uncomfortable machine rather than labor over a design problem with pencil and paper. As hardware costs drop, the computer will no longer be a luxury and the above factors will assume increasing importance. In our case they are crucial, for we wish not only to bring the user to the machine, but to draw him out as much as possible.

In the process of a particular session with the machine, there are techniques that can be employed to encourage the user to interact. He may be provoked into taking action by an unsolicited message. This may be some completely meaningless act such as ringing a bell, or it can be something more relevant. Pask has implemented a feature for his computer-aided instruction system whereby a subject matter expert entering information into the system would be offered an overgeneralization or extrapolation of things he had previously entered into the machine, prompting him into clarifying a point. Negroponte's URBAN5 system offered the user suggestions when it sensed that he was stymied.

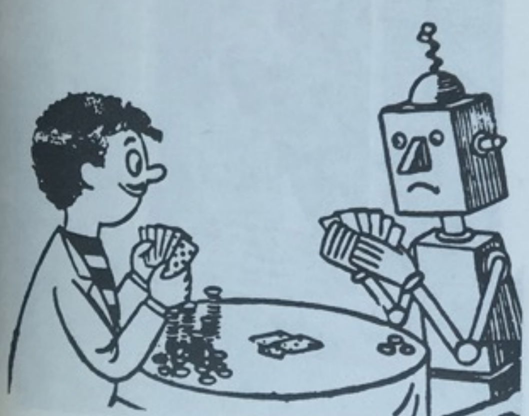
Foley, James and Victor Wallace, "The art of natural graphic man-machine conversation", in Proceeding of the IEEE, 62 (4), April (1974)

ACM/SIGGRAPH Workshop on User-Oriented Design of Interactive Graphics Systems, Pittsburgh, Pa., Oct. (1976)

Herot, Christopher and William Donelson, "Computer aids in mechanical design - a survey", MIT internal memorandum, (1976)

Pask, G., R. Bailey and R. Malik, "THOUGHTSTICKER manual", System Research Ltd., in press

Negroponte, N., "URBAN5 - a machine that discusses urban design", in "Emerging Methods in Design and Planning", Gary Moore (ed.), Cambridge, Mass.: MIT Press, (1970)

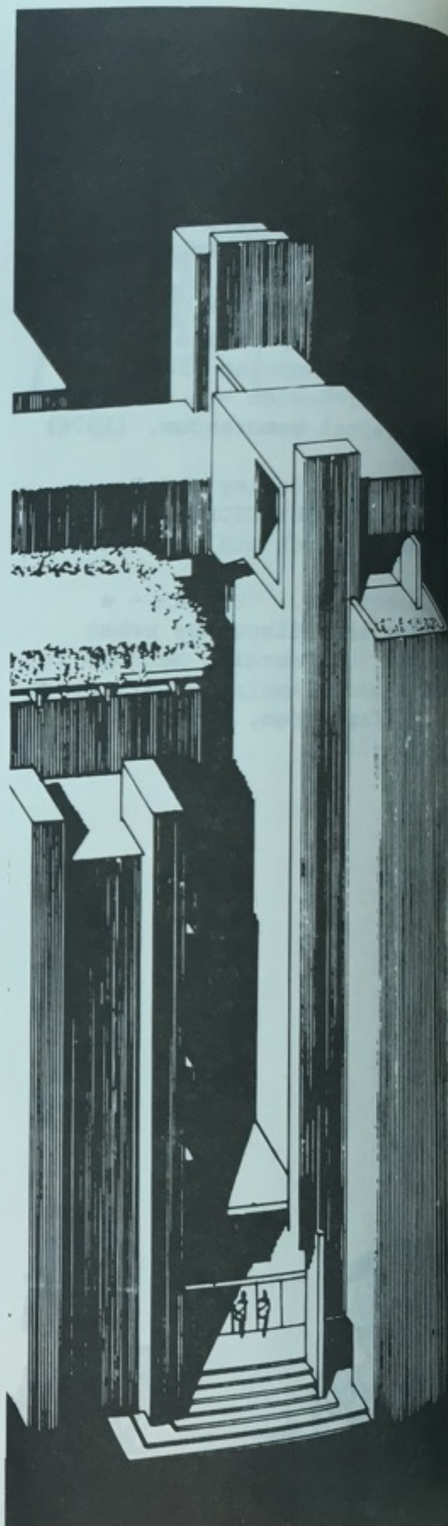


1.4.5 Exteriorization

Facilities for description and modeling influence the way a user thinks about a problem, and can have a profound influence on the outcome of the design process. The noted architect Charles Moore describes this effect in architecture and urban design:

> *Our techniques limit what we do, in the same way that any language limits what we think about. Our techniques also describe, by default, our goals. The standard instance, I guess, is zoning, which we must suppose was invented by city planners as a result of their use of Zip-a-tone, which is hard to cut unless your knife is sharp.*
>
> *Therefore, if you are describing urban land uses by applying colored Zip-a-tone, you are likely to assign greater virtue to large areas which do not need cutting than to nuisance-filled areas where a variety of contiguous uses would wear out the knife blade and the fingertip. You are likely to suppose, too, that streets, if they do not receive Zip-a-tone, form a logical dividing line between one use and another, though you will notice, if you look at any actual street, that they homogenize rather than divide. Thus goals otherwise untenable are created or at least arrived at as a result of the techniques we use.*

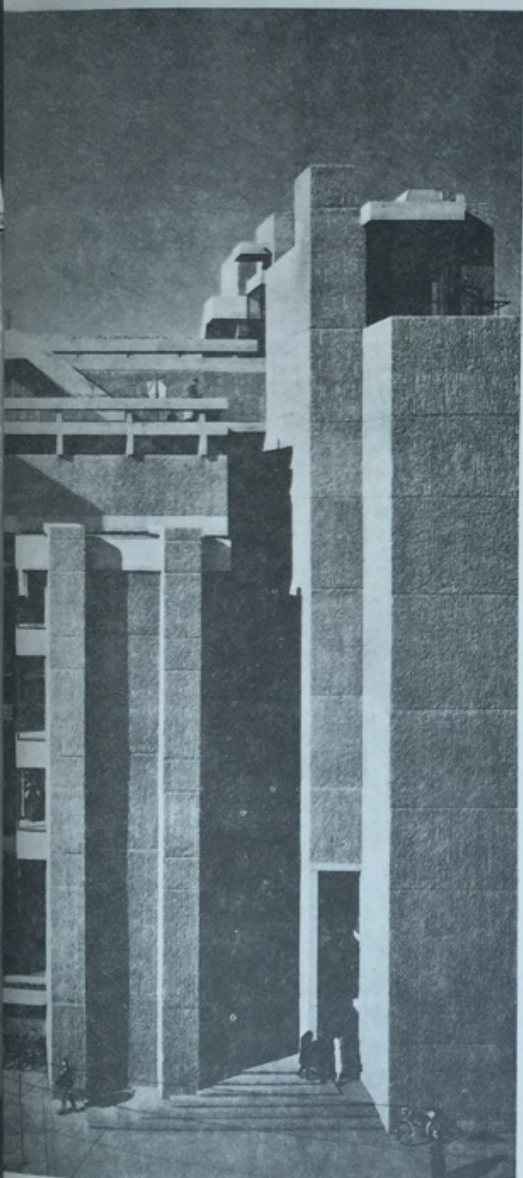
Newell and Simon demonstrate that drawings, models, and other physical representations are a powerful (and perhaps necessary) adjunct to most problem-solving tasks. The part of the mind that deals actively with problems has, according to these theorists, a limited capacity in terms of the number of symbols or "chunks" of information that can be handled at one time. For larger quantities of information, people employ abstractions, symbols, learned body movement, or external memory devices such as paper.



External representations not only allow the manipulation of large quantities of

Milne, Murray (ed.), "Computer graphics in architecture and design", New Haven, Conn.: Yale School of Art and Architecture, (1969), p. 97

Newell, A. and H. Simon, "Human problem solving", Englewood Cliffs, N.J.: Prentice-Hall, (1972)



data, but they permit the mind to draw associations in a powerful if unpredictable manner. Through associations made while viewing a drawing or model, a designer may be able to reorient his perception of a problem, generating entirely new approaches to its solution -- the "A-ha!" syndrome.

In solving a design problem, representations are chosen for their ability to model some useful aspect of the physical reality of the problem. They may simplify the problem, render it more accessible, or merely be less expensive or dangerous than reality itself. These transformations must relate the representation to reality in a useful way. In architecture, this may imply that the difficulty of expressing something in a model should be proportional to the difficulty of fabricating it in the proposed construction method. When such a close correspondence is achieved, the model can be a useful tool for exploring design alternatives as well as just a scratch pad to extend the designer's short-term memory.

Although graphics naturally lends itself to externalization of spatial information, as in architecture and mechanical design, it also can find more general application.

The PLATO system offers a medium for externalizing the learning process. As today's most facile embodiment of computer-aided instruction, it provides an extremely versatile terminal with plasma panel, microfiche, and touch input. In this environment the writing of an interactive graphics program to model a concept is a means of externalizing that concept. Even though the designers of PLATO intended the modeling process to be a tool for the use of the instructor, it has proved to be one of the more popular facilities with students.

The use of programming as a modeling technique is central to Seymour Papert's work in "teaching children thinking." The LOGO language is offered to the student as a means of exteriorizing concepts. The student regards the program as a model, watching it work, correcting it, and using it to provide explanations of cause and effect. The use of interactive graphics and input/output devices like the button box (where buttons can be pressed and light up instead of typing and reading symbolic names) provide a transparent interface to the model, such that the student can use his program as a descriptive tool.

The concept of simulation as a teaching tool is also found in Alan Kay's work with the SMALLTALK language. In this case, the language is explicitly designed for the description of arbitrary worlds. A central feature of the language is its capability for specifying the action of entities in the system.

Bitzer, D., et al., "The PLATO system and science education", Univ. of Illinois Computer Based Education Research Center, Report no. X-17, August (1970)

Papert, Seymour, "Uses of technology to enhance education", LOGO memo no. 8, June (1973)

Learning Research Group, "Personal dynamic media", Xerox PARC, March, (1976)

Miller, G.A., "The magical number seven plus or minus two: some limits on our capacity for processing information", Psychological Review, 63, (1956), pp. 81-97

1.4.6 Interpretability

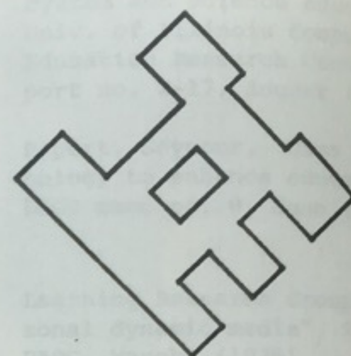
The exteriorization of cognitive processes that takes place when a person communicates through a computer makes those processes open to interpretation. The use of such interpretations to aid in problem solving is discussed in the next two subsections on transformations. In this section, we discuss interpretations done for the benefit of the machine or for the experimentalist who builds the machine.

Such interpretations can be used to discern what the user is trying to do and how successful he is at doing it. The heuristic tests of section 1.2, Conversation Theory, can be applied to verify that a series of understandings is indeed being achieved, that is, a conversation is taking place.

In a computer-aided instruction system this technique may be used to detect if the student is learning and to guide him to useful pieces of information. In the context of computer-aided design, the machine may need to make interpretations of user intent as a means of rendering the interface transparent (see section 3.3, Inference Making).

Marcell Marceau, the world-famous mime, speaks of different kinds of silences of his audience: approval silence, disdain silence, or boredom, all of which he can interpret without seeing them. This is an example of subtle interpretability, to be distinguished from current computer technologies, which struggle with the interpretation of the written word. This section alludes to a framework of interpretation that is easier for the machine, namely the drawing or the picture.

1.4.7 Tautological Transformations



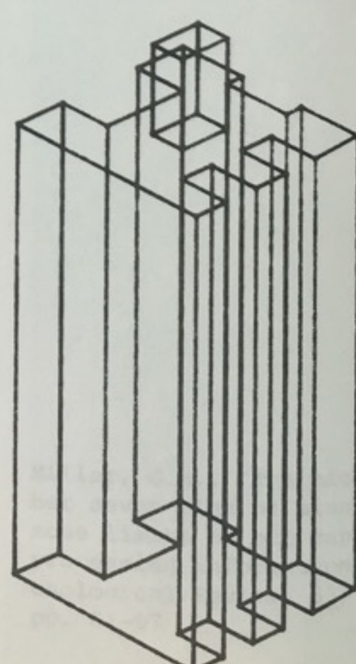
In his book *Cybernetics of Cybernetics*, Heinz von Foerster states that computers execute logical tautologies. These are transformations that result in no change of information content. Although such operations on English sentences usually produce boring results, tautological transformations of symbolic or graphical representations can be extremely useful. Such operations are difficult for humans to perform, while algorithms for doing them mechanically are well known.

Von Foerster, H., "Cybernetics of cybernetics", Bio-Computing Laboratory, Univ. of Illinois at Urbana, (1974)

Bogen, R., et al., "MACSYMA reference manual", Laboratory for Computer Science, MIT, (1975)

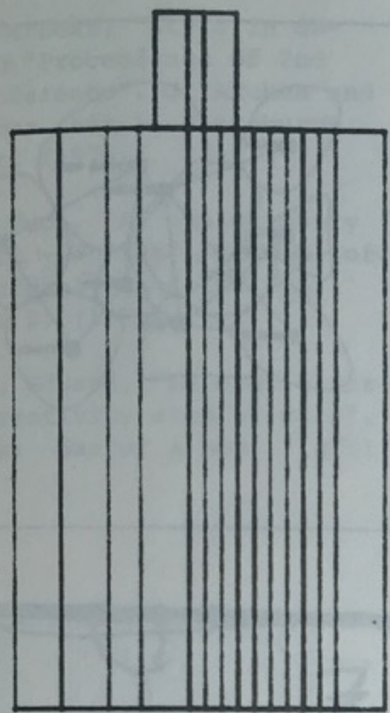
Tautological transformations are the meat of many interactive computer systems. Examples can be found in different fields. The MACSYMA system for solving mathematical problems derives its strength from the transformations it can apply to symbolic expressions. It allows the user to select the form he wishes to work with, even if the machine uses another form internally. The authors of that system found that the display format as well as the mathematical form of the expression was an extremely important factor in making the system useful to mathematicians.

In decision support systems it has been found that flexibility of display formats is an important property, especially when the decision-making process is not known in advance. The user may be offered a choice of tables, graphs, and charts, which he can choose from according to his specific needs at the time.

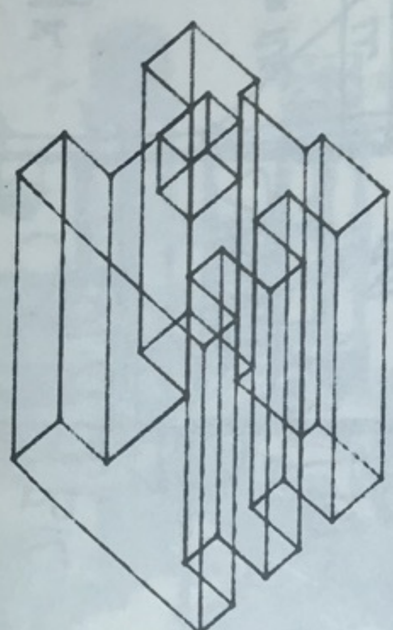


Computer-aided design systems have long exploited a range of tautological graphical transformations such as scaling, rotation, and perspective. The user of such a system can create a model in one view and then view the effect of his actions from another one.

The class of transformations discussed in this section are an essential aspect of any system for mediation of graphical communication. They are necessary to provide transparent access to information and they are central to many of the filtering and



Bennett, J., "User-oriented graphics systems for decision support in unstructured tasks", ACM/SIGGRAPH Workshop on User-Oriented Design of Interactive Graphics Systems, Pittsburgh, Pa., Oct. (1976)



personalization capabilities described in chapter 3.0, Mediation. A useful graphical communication system will have to provide such tautological transformations.

1.4.8 Non-Tautological Transformations

Non-tautological transformations are those that do result in a change of information content, typically by the addition of new information. These form a very powerful class of operations; they enable the discovery of analogies between different points of view, an important aspect of creativity and innovation.

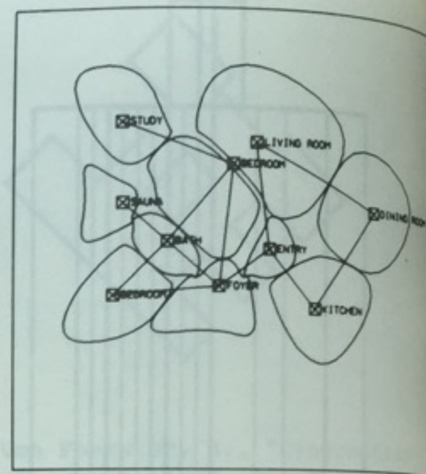
Non-tautological transformations fall into at least three categories, all important to graphical conversations:

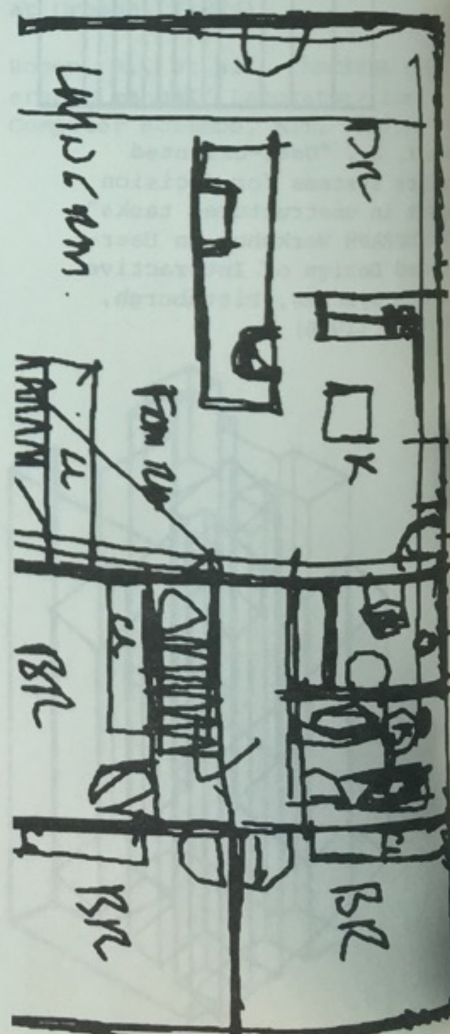
1. Changing specificity through new input.
2. Changing information availability by changing the medium of representation.
3. Changing information through associations and refutations.

1. Specifity through input. Many topics are like the tip of an iceberg. They represent entire domains of knowledge at a different level in a hierarchy of information. Transformations which change the viewer's level in that hierarchy necessarily cause an expansion of topics into descriptions.

An example of this class of transformation is found in the process of moving from diagram to scaled layout (be it for a house plan or printed circuit board).

There are two functions in this form of transformation. One points to the types of categories of information to be added. The other adds specific values to those categories. For example, in moving to a layout, categories of new information are pointed to: doors, wall thicknesses, window sizes and locations, etc. The values for these categories than are developed or derived. The power of graphical communication can be seen in the layout example, where the given diagram is displayed in proximity with a typical layout. Here the layout "points" to the

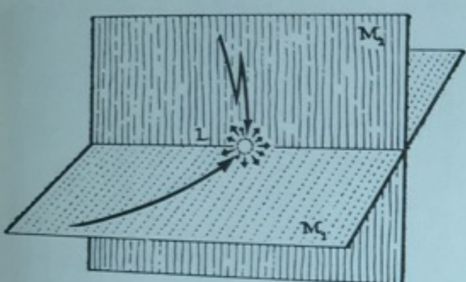




Simon, Herbert, "Style in design", in "Proceedings of 2nd EDRA Conference", J. Archea and C. Eastman (eds.), Pittsburgh, Pa., Oct. (1970)

Rorick, Huck, "An evolutionary architect - Wright", Journal of Architectural Education, 26, nos. 1 & 2, (1971)

de Bono, Edward, "Lateral thinking: creativity step by step", New York: Harper & Row, (1970)



Koestler, Arthur, "The act of creation", New York: Macmillan Press, (1964)

items required for increased specificity. Going further, our work in graphical input techniques points to potentials for the machine completing the layout, perhaps by showing a range of possible dimensioned alternatives.

2. Changing the medium. A concept is transformed non-tautologically as it is presented in different media: styrofoam, cardboard, color raster scan, vector graphics. This phenomenon accounts for the impact of the use of Zip-a-tone discussed in subsection 1.4.5. Since it is possible to model these media in a machine so as to perform these kinds of transformations (either on the basis of personal preference or on the basis of seeking clearer communication with others or with one's self). When dealing with graphical representations it is even possible to imbed the characteristics of style and use these to transform objects into the ultimate of media -- another person's hand.

3. Associations and refutations. Numerous authors have explored the power of associations. Their studies identify associations as the intersection of two previously unrelated concepts (a partial definition of conversation). And Koestler, especially, speaks of "bisociations" (his term) as the catalyst of innovation -- the joining of two unrelated notions to form a third, new, perception. Graphics are an especially powerful medium with which to convey or to spark associations, as witnessed in the impossible figures of Escher and others.

The liberal nature of the computer enables it to model and graphically represent a diverse range of concepts and worlds (not all of which need be drawn from reality as we know it). Further, given rules for their combination the machine can perform intersections for worlds. For example, our work in Architecture by Yourself (Appendix X) has produced a means of modeling bubble-like forms. This model is presently used for indicating room areas without imparting a shape bias. It is possible, however, to use this model in conjunction with the concepts of airframes to produce specific suggestions for derigibles. Thus, given a range of concepts which are especially well expressed in graphical modes, there is enormous potential for generating and conveying associations.

In summary, the non-tautological transformation is the essence of creativity. It is driven by the combined forces of serendipity and timeliness. The assumption that we can control creativity in graphical conversation would be laughable. We submit only that we recognize it and propose not to preclude it.

Newell, Allan and Herbert Simon, "Human problem solving", Englewood Cliffs, N.J.: Prentice-Hall, (1972)

Gregory, R.L., "Eye and brain: the psychology of seeing", New York: McGraw-Hill, (1966)

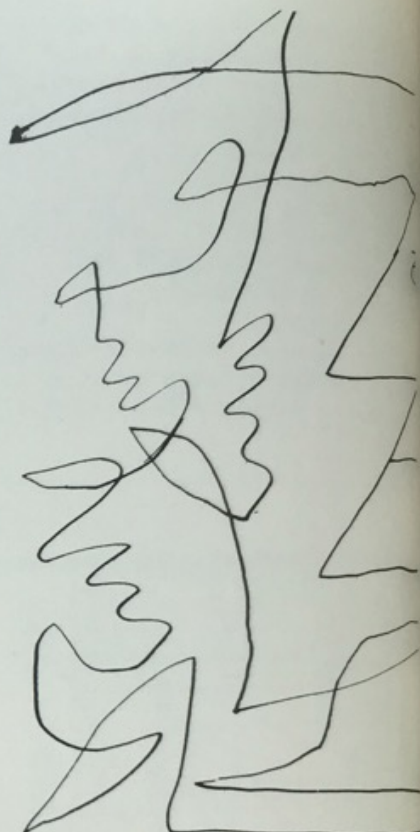
1.4.9 Series Not Sequence

We have argued that the power of a graphical conversation theory depends upon the processor residing at the man-machine interface. In particular, this processor must be so designed that it can be simultaneously inhabited by several programs (or "classes of programs," called "procedures") that operate independently of each other unless a coupling of some type is externally specified. Moreover, if such a coupling or association is specified and if it is orderly enough to promote coherent action, then the coupling itself is embodied in a separate element or partition of the processor as a procedure that sustains the coherency.

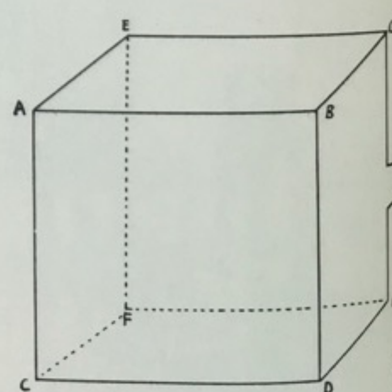
These facilities would be of only peripheral interest except to pure theorists in computer science if it were not possible to exhibit the activity of the several processors (or distinct parts of one processor) in an intelligible and manipulable manner; in the present state of the art we can only imagine the visual sense modality being used expeditiously for this purpose. But we *can* see and *realize* dynamic graphic facilities that do exactly what is required.

To the user, the proposed system thus resembles a multifacted visual display and control interface; from it, he may call for as many *a priori* independent computing machines as he requires to do the job. Moreover, he can look at, observe, program and give input data or instructions to any or all of these independent machines. When an association is ordained, a further machine ("active universe" might be the phrase preferred by a logician) is provided along with its own reserved display and control interface. This machine embodies the coupling or association between the operations already in progress and those juxtaposed. This similarity inheres in any analogical relation since an analogy comprises both a similarity *and* a difference or distinction.

Logically and computationally the crucial points are (1) that similarities may exist with equal rectitude and utility between means and between ends (or between "methods/procedures" and "descriptions/results" of executing procedures, and (2) that similarities and differences are generally determined by processes (rather than simple predicates or adjectives), so that, in the combination of similarity and difference, it is possible to specify analogies, and so on, without any but arbitrary limitation.

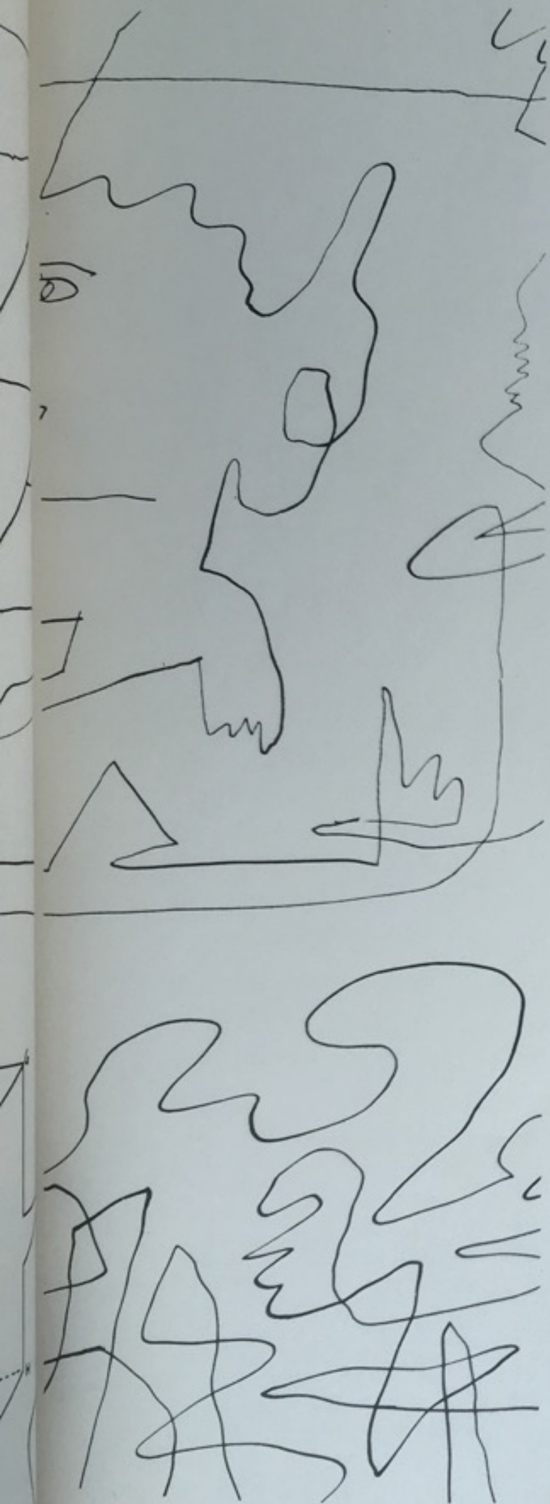


By these techniques (mustering processors or distinct and independent parts of one processor), participants, acting as users of the system, can express analogies; either those that they suggest of their own volition or those that are suggested by routines preexisting in the computer system (for example, the analogy inherent in a transformation between bubble-images on the dual of an incidence-graph and spaces on a floor plan). If the users converse with each other through the system, and it is the gist of our proposal that they do so, then such analogies appear to the users as the simultaneous presentation of disparate visual images (each connected to a reserved processor) and their subsequent association, coupling, or ordination of dependency, is realized in the displayed image of a further reserved processor.



It follows that such a conversation is no longer strict and linearly sequenced. Understandings occur in series but not in sequence. There is no necessary order determined between the topics related by a putative analogy before this analogy is known to be valid.

We submit that this is certainly one way in which to exteriorize the process of innovation/creativity/invention and conjecture that it is the only way in which to do so (notice that analogical reasoning, as used in this context, adumbrates types of reasoning that are often classed as inductive or even insightful).



1.4.10 Analogy as Ossified Agreement

An interface should be designed to encourage the participants in a conversation to exteriorize their cognitive and conative processes as a stretch of symbolic, but usually nonverbal behavior. Thus the previous subsection specifies the interface conditions that are a prerequisite for achieving a general conversation (section 1.3, in contrast to a strict and serial conversation between participants as noted in section 1.2). As noted in section 1.3, more than one participant may act independently, becoming dependent only if the conversation reaches partial (or complete) agreement. This possibility was previously set in the context of intrapersonal conversation, though it is equally relevant to interpersonal conversation.

With this comment in mind, consider the peculiarity of topics in the conversational domain (representations of knowledge) that are analogical relations between topics. Formally, the relation of analogy has a systemic similarity, depicted as a morphism, which in the strongest but least usual case, is an isomorphism. The similarity relates several other topics (call them X and Y) that are said to be analogous. Over and above this similarity, the analogy necessarily embodies a semantic difference, which is expressed by means of one or more predicates having values that distinguish universes (call them U and V) that are characteristic of the analogous topics X and Y. For example, X and Y may be a linear electrical oscillator and a linear mechanical oscillator; if so, the similarity is an isomorphism and the semantic distinction of the analogy consists of any set of predicates with values that distinguish between electricity and mechanics. Notice, however, that the morphism (similarity component) would not be an isomorphism for other than linear oscillators; nor would it usually be an isomorphism for analogues that exist between cities and urban plans.

To say that the participants A and B *understand* an analogical relation that *is pointed* out to them implies nothing that has not been previously introduced. On the other hand, to say that the participants A and B *construct* or *invent* or *create* an analogy (acting as theorists, designers, or subject matter experts building up a conversational domain) *does* imply that A and B regard the universes U and V of X and Y as *a priori* independent modeling facilities in which they may construct and reach agreement about working models able to simulate X and Y. This measure of agreement is reflected in the similarity said to hold between X and Y (the analogy in questions). Further, A and B are in a position to inscribe the *fact* of their agreement (in itself a dynamic process) as a static inscription, an ossified or fossilized remnant of the agreement they have reached. In this sense, all analogy relations arise from ossified, petrified, or fossilized agreements between participants.

Taking a more fundamental point of view, all analogies are ossified or petrified agreement left over as the dregs of a conversation which has taken place. To see this, notice that the most basic kind of independence between universes U and V (of X and Y) that might be conceived is no more nor less than the independence between brains, or parts of one brain in which A and B may coexist as independent participants. In other words, the underlying modeling facilities, U and V, are identified with these distinct brains or distinct parts of one brain. If so, analogies, on a par with X and Y, represent (in this curiously though conveniently static form) all possible agreements that may exist between A and B, and these agreements seem to lie at the root of any kind of innovation.

1.4.11 Concurrency in the Computing Process

Having made provison to accomodate the coupled execution of dynamic models, expressing an agreement between a priori independent participants, the same arrangements can be used to accomodate the coupled execution of any kind of concurrent computation, either in brains or in computers and other processors. In this connection, concurrency designates a simultaneous computation in which a conflict is resolved as part of the execution process (in contrast to parallel computation in which the absence of possible conflict is predetermined).

The provision is not trivial. In section 1.2 we sedulously avoided mention of conversation with rather than conversation through a computing machine at the interface. At this point, it is possible to relax the caveat, though not as yet to realize the consequences of that liberality. As a result, it is possible to contemplate (though again, not to realize) one route toward a genuine, rather than simulated and grossly mimicked, variety of artificial intelligence.

1.5 Intelligent Systems

In a study still in preparation to appear in 1977 (see Appendix XI), Marvin Minsky likens the manipulation of ideas to the manipulation of things, a concept that he calls a machine intelligence paradigm.

Similarly, in this section, we liken the representation of ideas to the representation of things; any idea exteriorized either for private or public consumption, imbibes the Gestalt of the mode and medium through which it is externalized. In short, the representation and the presentation are isomorphic. We argue that no concept is arepresentational inasmuch as it might be disjoint from the modes and media of representation. Much research on intelligent systems disregards or disagrees with this dependence and artificial intelligence techniques have suffered from a parsimony of dimensions of exteriorization and interaction.

"Intelligent systems" are the glue of this proposal. The eleven characterizations of graphical conversation in the previous subsections and the collection of tasks in chapter 5.0 are held together with structures that are in no sense simple, that are networks of procedure and relationships that live in what we are calling a "mesh."

We see our contribution to artificial intelligence as being the inferential methods that turn these methods into personal information spaces and that, consequently, allow a machine to act on the behalf of a user as his agent. This is not a scheme for representing knowledge, but a means of sharing that representation through graphical representations. Although seemingly recursive and tongue twisting, this is more than just one step back, because the shared graphical representation is between a machine and a person. In half seriousness we can postulate a graphical Turing test on something like Scribblephone (subsection 5.4.1), namely, when an individual calls another individual and they have a convincing graphical conversation, but one is not at the other end, his machine is. Such is implied on the cover of this proposal.

The extravagance of this example is important to introduce the next three subsections. In the first we shelve the notion of talking with a machine as a conscious and purposeful mechanism. We distinguish "through" from "with," arguing that "though" is both feasible and does not preclude "with." A 1982 follow-up proposal to this work may well be less modest about the "with" issue.

The second subsection explains our approach to structuring knowledge with reference to the literature, using "entailment meshes" as our in-house title for subject representation.

The last subsection in this introductory chapter remarks briefly on "recognition." "Recognition" plays two roles: (1) that of compressing incoming signals, like the multitude of data tablet samples into a wire-frame 3-D intention, and (2) that of expanding signals, like a single gesture, into *turn the page and delete all occurences of "string" to "strung" when it follows a proper noun that is not the name of a country with political affiliation with any oil-producing nation of the Western Hemisphere.*

1.5.1 Through Versus With

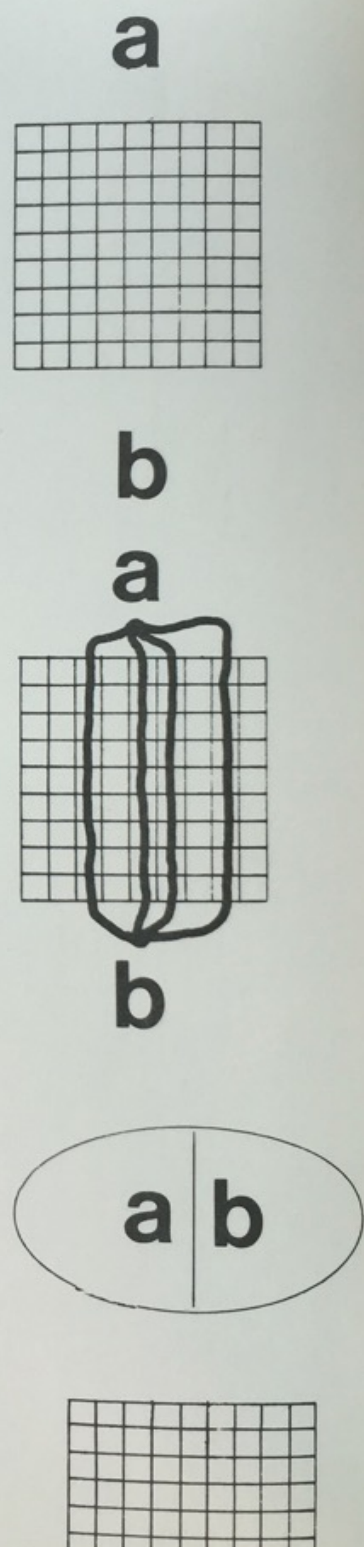
The distinction between interpersonal an intrapersonal conversations (section 1.3) raises a specific issue: In what circumstances is the computer a link in the chain of communication and when is the machine itself an equal participant *in* the conversation? What is the distinction between conversation *through* a machine and conversation *with* a machine?

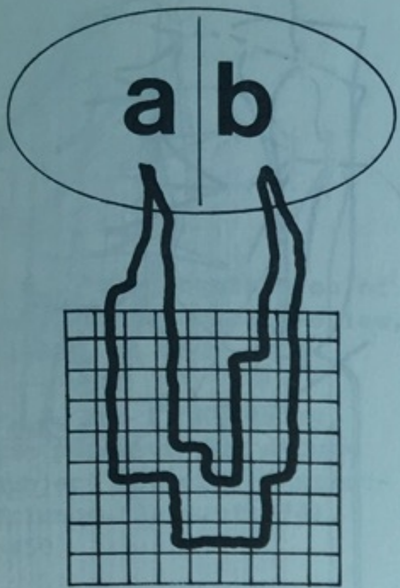
These issues must be addressed within not only the scope of this proposal but also in the wider context of ten and twenty years hence. These distinctions will become crucial when machine-based cognition becomes feasible. Careful application of the terms will preserve the impact of conversations *with* a computer for a later time.

With the system proposed in section 1.4, Characteristics of a Graphical Conversation, we have the capability of initiating a highly formal and specified "conversation" as formally and specifically defined in section 1.2. Consider the paradigm of two independent systems engaging in these activities: One way in which A and B might interact is through the mediation of a machine (the term "through" is clearly appropriate in this case).

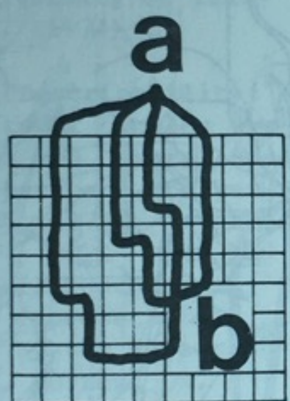
Now consider the probable situation in which A and B are part of the same brain, i.e., are in the mind of one individual. Without some encouragement to interact (subsection 1.4.4), the figure is a model of an individual sitting and thinking. Once coaxed, the threads of cognition drawn out of the individual and into the machine can be studied and understood (subsection 1.4.5, Exteriorization).

In each of these cases, the loci of control, A and B, are part of the individual(s) who interacts and converses. The reference to conversation *with* a machine must be reserved for the instance in which the locus of control is embodied in the machine.





This proposal clarifies and quantifies conversations through computers, which act as mediators between individuals (interpersonal) and within individuals (intrapersonal).



Pask, G., "Conversation, cognition, and learning", New York: Elsevier, (1975)

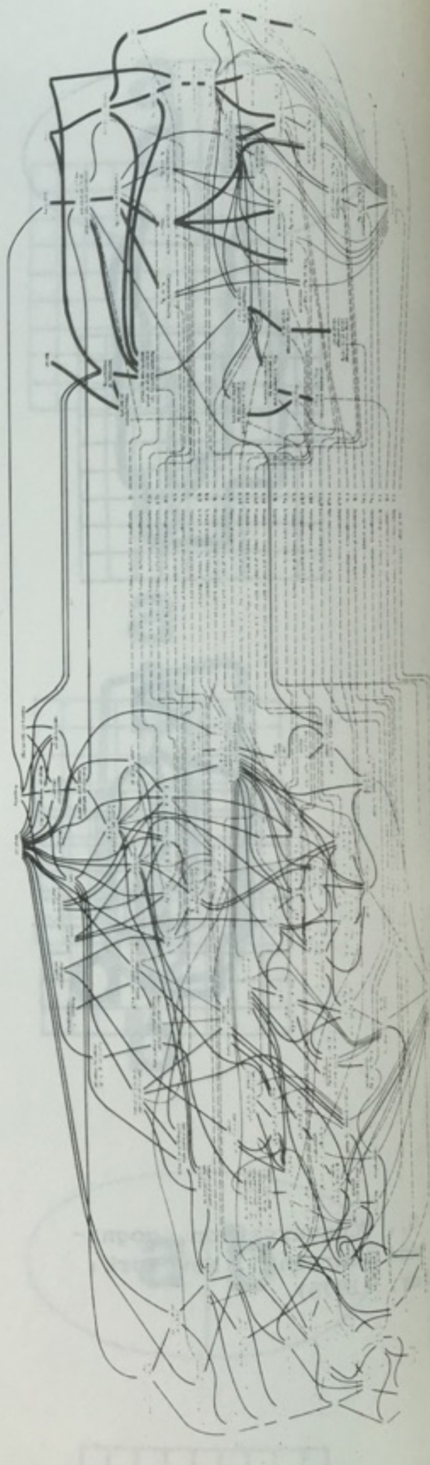
Pask, G., "Position paper for conference chaired by Gregory Bateson", Co-Evolution Quarterly, (1974)

1.5.2 Entailment Meshes

Gagne was the first modern psychologist to propose an explicit structure of knowledge. True, the idea that knowledge has a structure had been bandied about since the Middle Ages and actualized by artifacts such as "memory theaters" or the Lullian "ladders of Heaven." Nevertheless, these ingenious contrivances were of primary value to orators, merchants, and the casual audience of rhetoric schools. Gagne surely clothed the notion of structure in up-to-date costume; this was a significant innovation insofar as it allowed him to examine problem solving (notably, number series completion). But the garments he selected for this purpose, though tailored to provide orderly data, were rather too restrictive to accommodate all the types of cognition and learning manifest in everyday, as well as creative, affairs. The constraint (though surely not the defect) of this scheme is its restriction to a hierarchical organization. Hierarchies are also obtrusive in the directly axiomatic representations of knowledge proposed by Kingsley and Steltzer. Recent work by Steltzer rescinds the hierarchical constraint and admits analogy relations that are, as a matter of form, essentially cyclic. However, the bias toward hierarchies persists in educational science and psychology. It is expressed by postulates like course "prerequisites" or "behavioral objectives" to be achieved in stepwise progression.

Hierarchical limitations are present in the earlier essays of artifical intelligence and educational psychology (often homogenized as "cognitive science"). Hierarchies do not lack merit and are in fact useful for specific, local purposes. However, as later investigations have shown, they are not indispensable; our argument relies heavily on this fact, which is clearly demonstrated by much recent work.

Knowables (loosely "knowledge"), as seen by these authors, are represented



procedurally; that is, in terms of computing processes. The same theme permeates the thinking of Von Foerster and others concerned with memory as a kind of recomputation, or reconstruction, or reproduction of concepts (a recurring idiom in this proposal). Our initial disposition in this matter is to accept the scheme of knowledge representation of Pask, Kallikourdis, and Scott. This scheme is compatible with the other schemes cited and also with the work of Varella, Matturana, and Klir, but it is more readily implemented since computer-programmed realizations are immediately available. Such representations of knowables are immediately available. Such representations of knowables are termed "entailment meshes" and consist of a directed graph with nodes that stand for topics and arcs that specify the relations among topics. The entire "entailment mesh" is cyclic (reentrant or recomputable without loss of specificity) except for primitive predicates forming the distinctions that underlie analogies (subsection 1.4.9) and primitive functions that are the translations of instructions accepted either by a particular machine or an individual mind (the idea that different individual minds may accept quite different instructions, primitive functions, and already understood concepts is understood).

Although an entailment mesh is cyclic, it is possible to distinguish conjunctive (T is entailed by P and Q), disjunctive (T is entailed by P and Q or R and S), and analogical relations among topics represented by its nodes. Moreover, some analogies are one-to-one isomorphisms. Choosing a topic that is a simple or an isomorphic analogy, the mesh may be pruned under this topic in order to delineate a particular perspective about the subject matter. Thr pruning operation yields a quasi-ordered "entailment structure" (described in subsection 1.4.11 as a union of trees). Thus, entailment structures are specified for and on behalf of the participants in a conversation; they are, in this sense, personalized.

Gagne, R.M., "The acquisition of knowledge", Psychological Review, 69, 4, (1962), p. 352

Steltzer, J. and E. Kingsley, "Axiomatic paradigm for structuring subject matter", Instructional Science, 3, 4, (1974), pp. 383-450

Von Foerster, H., "Cybernetics of cybernetics", Bio-Computing Laboratory, University of Illinois at Urbana, (1974)

Loefgren, L., "Describability and learnability of complex systems", Automata and General System Science Department, University of London, (1976), in press

Pask, G., D. Kallikourdis and B. Scott, "The representation of knowledge", System Research Ltd., Richmond, Surrey, UK, (1973)

Maturana and Varela, "Autopoietic systems", memo 94, Bio-Computing Laboratories, University of Illinois at Urbana, September, (1975)

Norman, D.A., D. Rumelhart and the LNR Research Group, "Explorations in cognition", San Francisco: W.H. Freeman, (1975)

Within the field of entailment structures (rather than entailment meshes) we distinguish several main varieties of analogy. The principal categories (other depend upon the strength of similarity and the predicates distinguishing semantic differences) are (1) analogies due to a similarity of ends, results, or descriptions of topics and (2) analogies due to similarities of method, means of attaining the stipulated end, or program structure under the given perspective. Both kinds of analogy are mechanically derivable and can be usefully implemented by existing computer programs.

This philosophy underlying this type of knowledge representation is that knowledge does not exist in a vacuum. It is engendered or produced by a conversation participant acting in the role of an expert who expounds a thesis, namely, the content of what he believes to be knowable or what he conceives as an innovation (invention, creation, design, etc.). There are no knowables without the minds to know them and there is no depersonalized knowledge. Machines may be programmed to operate upon knowables and are often used, for example, to render overgeneralizations for the purpose of provoking experts into further activity in which the experts refind a description by providing qualifying information. Machines may even do more than that (as tentatively posited in subsection 1.4.11), but this remains an open question.

Two issues are outstanding: How does someone access the topics in an entailment mesh? And what is the nature of a topic?

The first issue is resolved by recourse to a description scheme that may either be based upon the "semantic differential" paradigm (subsection 2.1.1) or the "repertory grid" (subsection 2.1.2) where "topics" are used in place of "objects" and are presented in systematic order. The latter expedient is preferred, since it individually indentifies those predicates that are regarded as primitive by a participant and those functions or instructions that are unto themselves primitive concepts.

The problem of defining the nature of a topic can be tackled in several ways. For example, an entailment mesh represents derivations (section 1.2) among topics that are proper to a thesis. However, each topic is associated with a certain class of explanation (section 1.2) that may be depicted as a class of programs which implement a description scheme. The mesh is defined as cyclic and consequently reconstructible or reproducible without loss of specificity. The condition that the mesh is cyclic is demanded of all local or immediate derivations. T is derive from/entailed by P and Q or T is derived from/entailed by R and S, for example, imply that given P and T, Q is derivable, given Q and T, P is derivable, given T and S, R is derivable, and given T and R, S is derivable. However, "other-than-local" cyclicity is both possible and common in practice. When it exists, the cyclic structure may be simplified and designated by one node in a distinct (condensed) entailment mesh, the nodes of which represent condensations of a submesh of the original mesh.

The simplifying operation of condensation can be repeated without limit. Moreover, its definition is recursive. As one consequence, the original mesh (which exists at an arbitrary grain or value along a dimension of molar-molecular or micro-micro specificity) has nodes that designate topics that are condensations of the class of explanations attached to each node. These "original" topics must be given a semantic interpretation in universes proper to whatever scheme of description can be applied if the mesh is converted into an entailment structure.

Minsky, Marvin, "A framework for representing knowledge", in "The psychology of computer vision", P. Winston (ed.), New York: McGraw-Hill, (1975)

"KRL", Language Research Group, Xerox PARC memo, (1975)

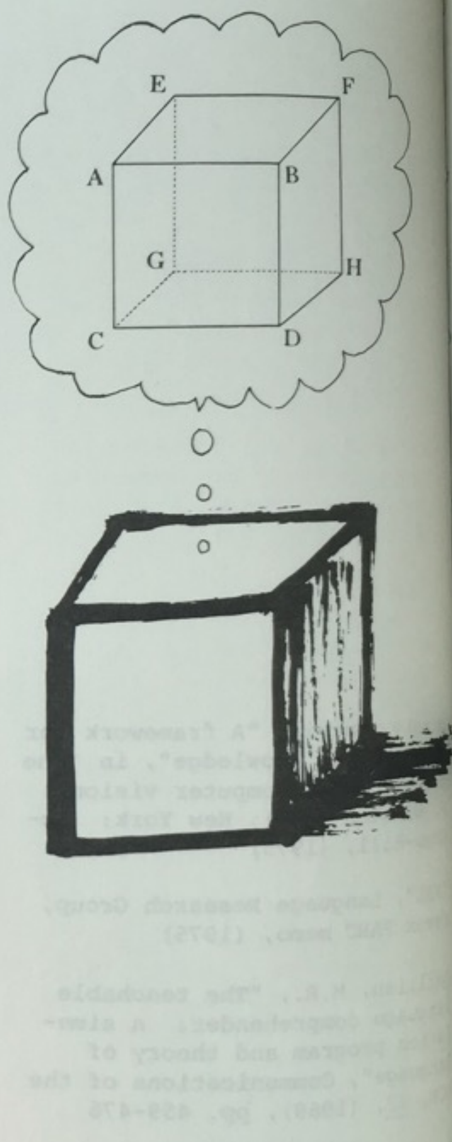
Quillian, M.R., "The teachable language comprehender: a simulation program and theory of language", Communications of the ACM, 12, (1969), pp. 459-476

Collins, Allan and Marilyn Adams, "Teaching causal knowledge and reasoning", Proposal to ONR, Bolt, Beranek, and Newman, Cambridge, Mass., (1976)

Goguen, J., "Hierarchical, inexact data structures in AI problems", AI memo no. 5, UCLA Computer Science, (1976)

1.5.3 Machine Recognition

Machine recognition is the structuring of unstructured data, usually decreasing its quantity while increasing its quality. The input data may be data points from a vidisector or drawing tablet or English sentences typed at a terminal. The result is some internal representation that embodies useful information about the object seen, drawn, or written about.



Recognition programs make extensive use of rules that express the natural constraints of the system supplying the input data. In natural-language input this may be an augmented transition network. In machine vision it may be a description of legal configurations of lines, vertices, and shadows. In sketch recognition it may be a description of valid geometries of floor-plan configurations.

In the proposed research, machine recognition is the process by which the graphical actions (utterances) are matched to the previous entailment mesh. It is this matching that enables a user to revisit topics and direct the conversation. The correspondence also permits the mediation of conversations as discussed in chapter 3. Finally, we submit that machine recognition and inference making is a prerequisite to the desired level of transparency of both the interface and the medium.

Machine recognition of graphical actions differs from other recognition problems in two very important ways, both of which are the result of the user's involvement in the process. The first difference is that the recognition process is interactive. The user can receive immediate feedback on the machine's interpretation of his actions. The level of recognition by the machine and the level of explicitness of the user's actions can be closely matched. This property connotes a smooth progression as the capabilities of the machine are expanded.

The second difference is that of information availability. If a human observer is not present at the time a sketch is made, he does not have access to such variables as speed or even sequence. Even if the observer is present, he probably cannot determine pressure and surely cannot record galvanic skin response of the subject. Such information is frequently that which is used by the computer to disambiguate information.

Our work in sketching has included 3-D mapping from a 2-D planar graph. This is much easier than the general machine vision problem for all of the above reasons. Precisely: one has sequence of strokes, which can resolve intended continuations (as in the adjacent diagram).

In addition, we can benefit from the idiosyncracies of the user, knowing how, for example, he or she draws. Drawing style is now set forth in this section as evidence -- that is, a heuristic of recognition --- rather than solely as something to make the user's life more comfortable. This is an important corollary to previous sections. We contend that many of our algorithms of cognition will use information about the user to do the recognition work.

2.0 INTERACTION

2.0 INTERACTION

Much of computer science continues to view interaction simply as quick turnaround -- being "on-line." We view interaction, instead, as a window between simulataneous processes dealing with a common topic, as the mutual feedback that modifies processes in progress. The distinction is critical. This section underscores that distinction, drawing upon insights gained during the past six years of research in this area. The following sections address specific factors critical to the new work proposed.

Having no prejudice of context, the dictionary defines interaction as "mutual or reciprocal action or influence." The symmetry of this definition tolerates the views sketched above. Unfortunately, "reciprocal action" and not "mutual influence" is the interpretation more commonly implemented. We say "unfortunately" because the "tit-for-tat" nature of such systems is more disruptive than helpful in settings where the user's objectives or intentions are not well defined and where the task is a search for agreement and consistence in converstions. By implicitly or explicitly forcing the user to initiate a machine action, then to wait for its completion, this form of reciprocal interaction reduces the user's role to that of manager and effectively removes him from participation in the process.

Simply being "on-line" is insufficient for "mutual influence." To achieve that level of interaction, several additional conditions must be satisfied:

1. All parties must be able to work on the same task simultaneously;

2. Each should be able to witness the actions of the other actors; and

3. Each should have the power to modify the state of the task -- to change the direction of the conversation.

The product of these conditions is feedback of the most essential kind. Each actor sees the consequences of his actions reflected back to him through the actions of the other actors.

The following sections expand the concept of interaction to include means for its measurement, approaches to classifying the subjects addressed, mutual cognizance between the parties involved, and their physical relationship to the referents and the power of the medium involved in the diaglogue. It should be noted that section 2.1, Measures, and section 2.2, Referents, are two different perspectives of the way in which people classify the subject matter with which they deal. Both of these views are necessary to understanding. Both begin with an act of "indication" leading to a "distinction." Section 2.1 moves from the acts of indication and distinction to objects and universes in the form of a caluculus. Section 2.2 views these acts as the events from which language arises.

Weinzapfel, Guy, "It might work but will it help", Proceedings of Design Activity International Conference, London, (1973)

Brown, G. Spencer, "The laws of form", International Journal of General Systems, 2, (1975)

Varela, Francisco, "A calculus for self-reference", International Journal of General Systems, 2, (1975)

2.1 Measures

The term "interactive" is a common one in the literature of computer science, especially in graphics. Since the first interactive graphical system in 1963, Sutherland's SKETCHPAD, the term has not advanced in meaning. Recent uses frequently mean less. We often hear the term interactive applied to systems that are clearly only "on-line" or which trivially utilize light pens and menus instead of typed command strings.

Sutherland, Ivan, "SKETCHPAD: a man-machine graphical communication system", Ph.D. thesis, MIT, (1963)

Sprecher, Leo, "Interactive computer graphics for assisting human programmers", Computers and Graphics, 1, London: Pergamon Press, (1975), pp. 17-20

Our laboratory has come to expand the term to include all aspects of the man-machine interface: hardware, software, environment, and concept (Appendices III, IV, VI, and VIII). Increasingly we see that a unified approach to interactive systems is the only means to understand and achieve quintessential relations between man and machine.

Section 1.5.1 diagrams instances in which there is interaction:

1. Between two persons, who use the machine as an intermediary.

2. Between an individual and himself, relation through the machine.

3. Between an individual and the machine, defined as conversation with a computer.

These three sets are different applications of systems that we call interactive. This section of the proposal is an exposition of two means to clarify and define in a formal way our meaning of the term "Interactive Systems." These models provide a basis for unified understanding and make possible the precise measurement of the quality and quantity of interaction in <u>any</u> man-machine relationship. This metric of the dynamics of an interactive system supplies the necessary yardstick with which to evaluate any implemented or proposed system, from morse code and Scribblephone to drawing with your eyes and conversational graphical communication.

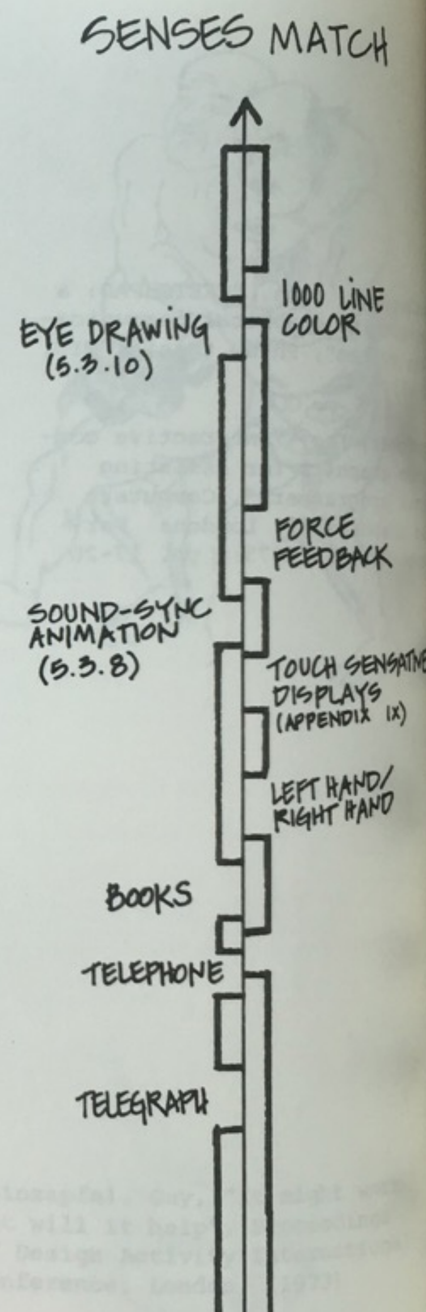
2.1.1 Semantic Differential

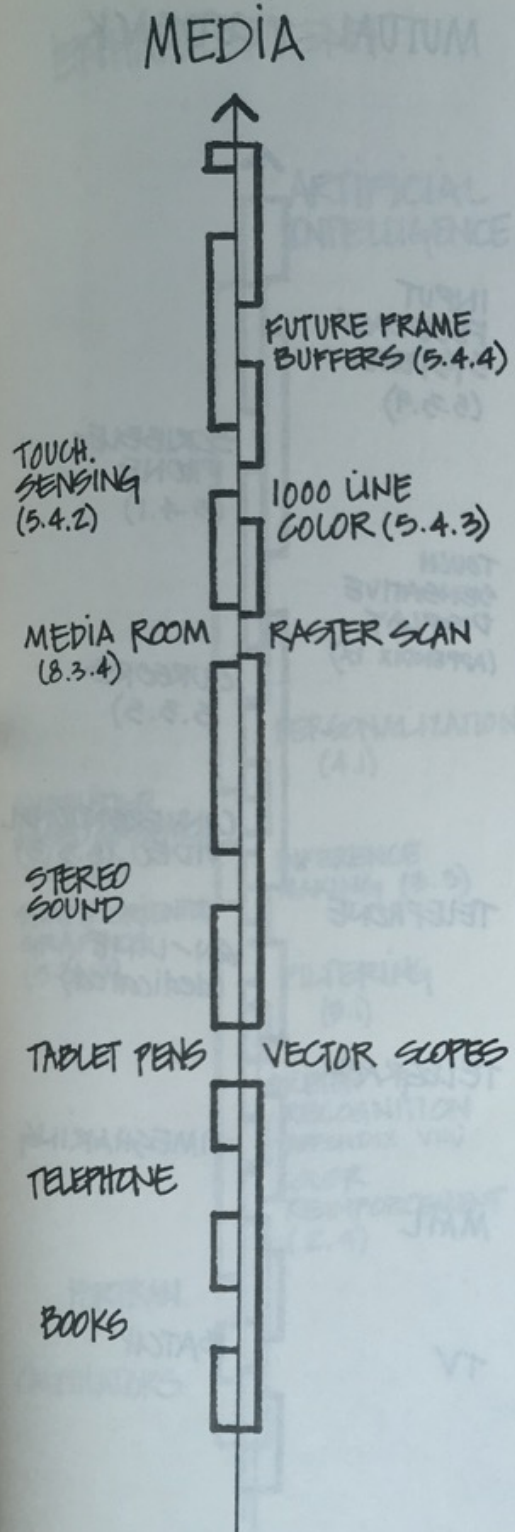
One straightforward way of getting a sense of the nature of any space is to assume a set of orthogonal axes, and place objects into that space. When measuring interaction, we consider representative systems that are in use, that have been constructed, and that will be construct. Placing them into the Euclidean space, at first informally, serves to expand the meaning of interactive systems. Later in this subsection, a formal methodology for this type of understanding, called the Semantic Differential, is outlined.

A first set of axes are:

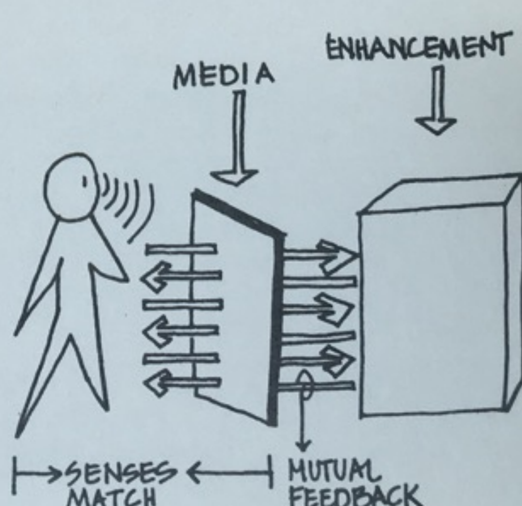
Senses matching
Media
Mutual feedback
Enhancement.

Senses matching: This axis is that of unenhanced perception: from being within hearing distance of a shout to eye-contact and physical touch. Drawing on a person's repertoire of real-world behavior models, user-interfaces for particular applications can be made facile and easy to use. The more "natural" by the criterion of "like the real world," the greater the interaction is possible. Telephones, for example, are ergonomically designed, but the need to hold them just to be able to talk and listen is an incumbrance. Using a touch-sensitive display with just a finger is so much more natural than using a light pen. The more facile the device is to use, the more interactive.

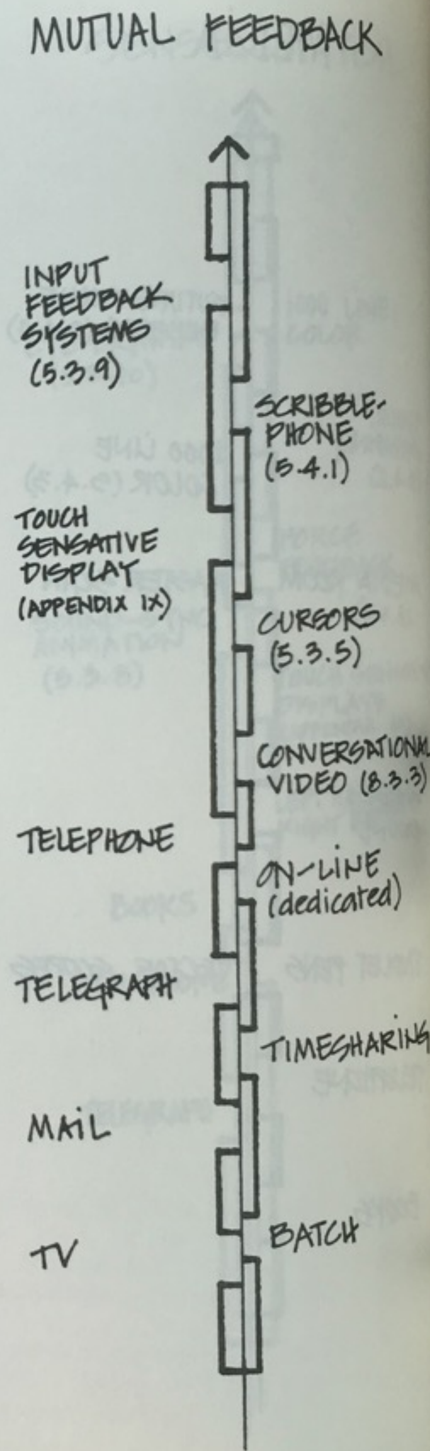


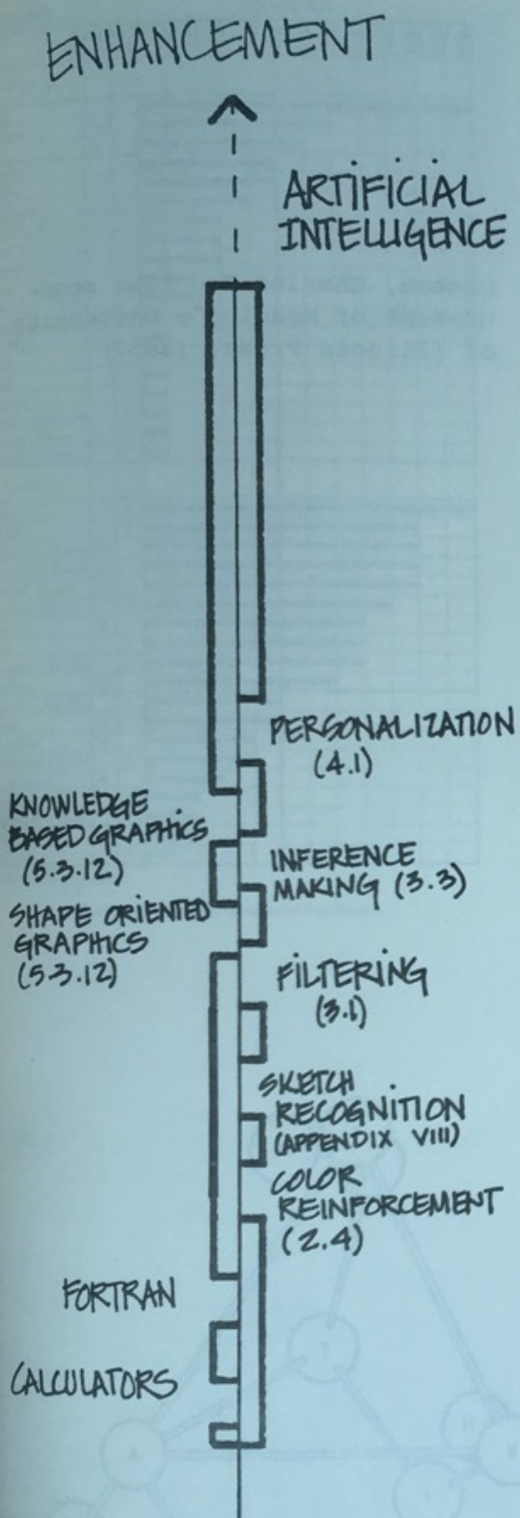


Media: The input/output (information) interfaces, whether objective (bandwidth measures) or subjective (psychophysical factors), are the active elements under consideration on this axis. The bandwidth limitations chosen for the telephone, for example, are reasonable when considering the frequency of speech; however, the quality of the sound remains poor, and limit the way the interaction "feels" subjectively. Current implementations of touch-sensitive displays lack the resolution of tablet pens, and hence are not as interactive when measured on the axis of media.



Mutual Feedback: Feedback can be defined as the rate of exchange of the initiative in a dynamic interchange. Note, as shown in the figure, that although the measure of feedback in increasing orders of interaction begins with cycle times of the communications link, context becomes increasingly dominant in determining what is "more" interactive. The implication is that the axis itself is insufficient to encompass the dynamic quality of interactive systems. It is interesting to note in the figure the position of "on-line" and "time-sharing," particularly since these two are frequently misunderstood as constituting interactive systems in and of themselves.





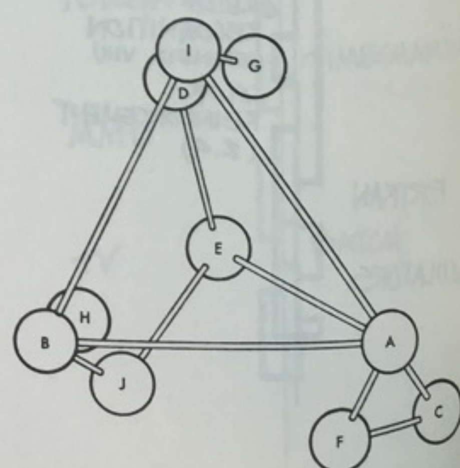
Enhancement: This is what a dynamic system/medium offers to enhance interaction. The addition of the powers of machines to create conceptual worlds and complex dynamic systems explodes the idea of media. Before this addition to the space of interaction, there could only be communication channels, bandwidths of electronics, audio versus video considerations. This axis offers the capability to expand interpersonal and intrapersonal relations beyond current limits. The figure offers a suggested placement of past and future work. More precise metrics of the space are needed, however, to more clearly position the effect of these enhancements on the interactive space. This is the second instance where the static Euclidean model is insufficient to the understanding of interaction.

With this broadened view of the meaning of interactive system, the priorities of man-to-man and man-to-machine relations can be assigned, for which a formal technique exists. Charles E. Osgood, in *The Measurement of Meaning* describes the process.

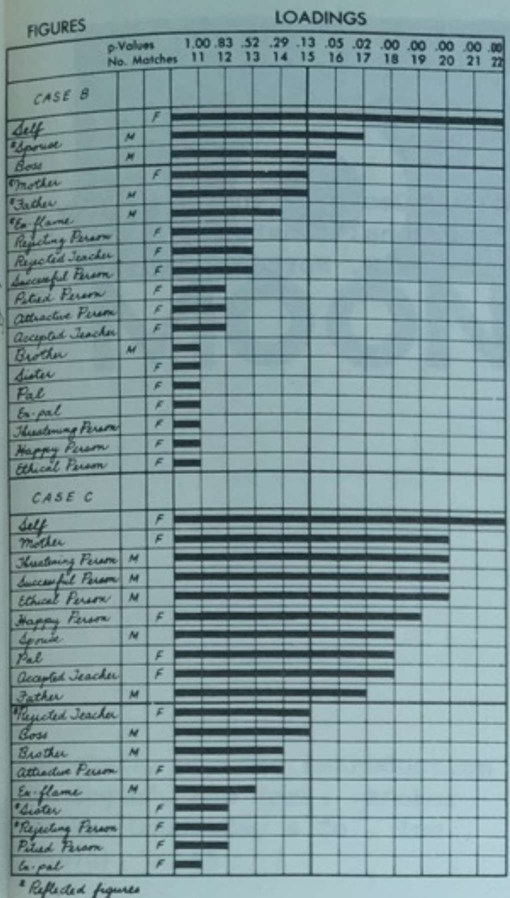
> *We begin by postulating a semantic space, a region of some unknown dimensionaltiy, and Euclidean in character. Each semantic scale, defined to be a pair of polar (opposite-in-meaning) adjectives is assumed to represent a straight line function that passes through the origin of this space, and a sample of such scales then represents a multi-dimensional space. The larger or more representative the sample the better defined is the space as a whole.*

Osgood, Charles E., "The measurement of meaning", University of Illinois Press, (1957)

Each point in space has a direction from the origin, which Osgood calls the quality, and a distance, considered to be the intensity. The entire schema is straightforward, and culminates in factor analysis to simplify the set of axes involved.



Drawing of three-dimensional model constructed from distance measures. Variables D, G, I (HERO, VIRILITY, SUCCESS), B, H, J (WHITE ROSE BUDS, GENTLENESS, SLEEP), A, C, F (QUICKSAND, DEATH, FATE), and E (METHODOLOGY).



Comparison of the Self-Identifications of Two Women.

2.1.2 Repertory Grids

Limitations of the semantic differential are the static, Euclidean nature of the modeling and the a priori determination of distinguishing features of the space.

George A. Kelly, in *The Psychology of Personal Constructs*, developed a method called repertory grids. This technique contains in its methodology the action of eliciting appropriate properties from the persons themselves. If one agrees that a person uses properties to distinguish objects from other objects, this method provides a better model of personal constructs, and hence a better measure of interpersonal or intrapersonal interactive systems.

Briefly, the mechanics of the method are: present to an observer a given universe of objects (in our application, all modes and modalities of interaction) and ask that they be grouped and distinguished in some way. After many different subjects of the universe of objects are submitted for evaluation, properties are built up until no new types are elicited. A grid is then constructed that consists of value assignments for each property (e.g., has, has not). Using techniques such as factor analysis and correlation on this grid yields an ordination set of the data. A super-ordination is constructed by asking why the constructs (properties) are different, and sub-ordination is built from how they are different.

This complex net of relations serves as a dynamic system. A change is made in the grid construct; call this change an implication. The change is rippled through the entire mesh by iteration and reduction. If this process realizes a stable situation in the construct, that is, if it converges, then a valid measure of the meaning in the system has been made.

Kelly related this technique to psychology and clinical models of personality. It has also been successfully employed in examining architect-client relationships and communications.

Abel, Chris, "Architrainer: an instructional game for architects", Architecture Machine internal memo, MIT, (1974)

> *Not only can the grid notion be generalized to all conceptualizations, but this mathematical notion can also be generalized .... This cybernetic model permits us to scan any grid with a hypothetical scanning pattern and note the concurrences of incidences ... . Thus we may have a mathematical basis for expressing and measuring the perceptual relationships between the everts which are uniquely interwoven in any person's psychological space.* [*The Psychology of Personal Constructs*, p. 268]

Serving as a formal basis for theoretical inquiry, a model so constructed provides swift and accurate evaluation of any proposed interactive system or change to a system.

Such full understanding of interaction (globally in a formal sense; from the test bed of a model; and the actual implementation of such systems as outlined in this proposal), leads to the establishment of priorities in all future man-machine relations, as well as the capability for accurate and reliable evaluation of all systems. The essence of success is the quality of the relation between human and computer. And this, we submit, is <u>all</u> interaction.

Kelly, George, "The psychology of personal constructs", New York: W.W. Norton, (1955)

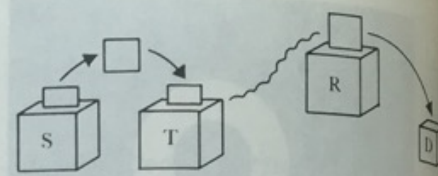
2.2 Referents

In elementary logic, an appropriate way by which to address the thorny problem of the logically ambiguous sentence is to try to close in upon its referent(s). Logically ambiguous sentences abound, usually arising from the fact that in English, as well as other languages, the self-same verb is used to express both predication and existence. Take the verb "is", for example, and the sentences "There is a God," and "God is just." (Contrast this with the sentences, "There are unicorns" [existence], and "Unicorns have horns" [predication].) We may note the classic case of Descartes' assertion "I think; therefore, I am," which inextricably confounds predication and existence. Although there is no sure way through the logical thicket, an analysis that asks, "What thing (if anything) is here referred to and what is asserted about it?" (Mitchell, 1970, p. 85) can serve to direct us to the right path.

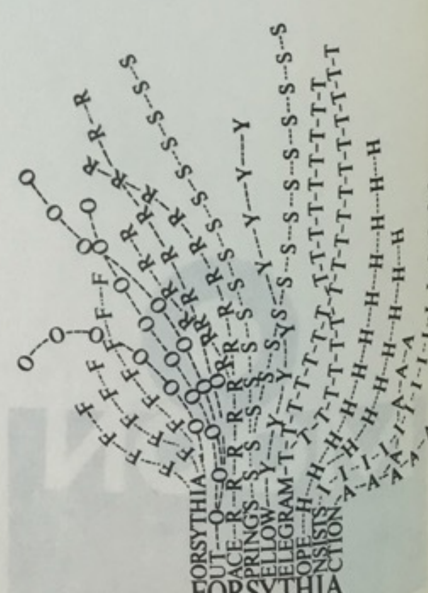
Mitchell, D., "An introduction to logic", New York: Anchor Books, Doubleday & Co., Inc., (1970), p. 85

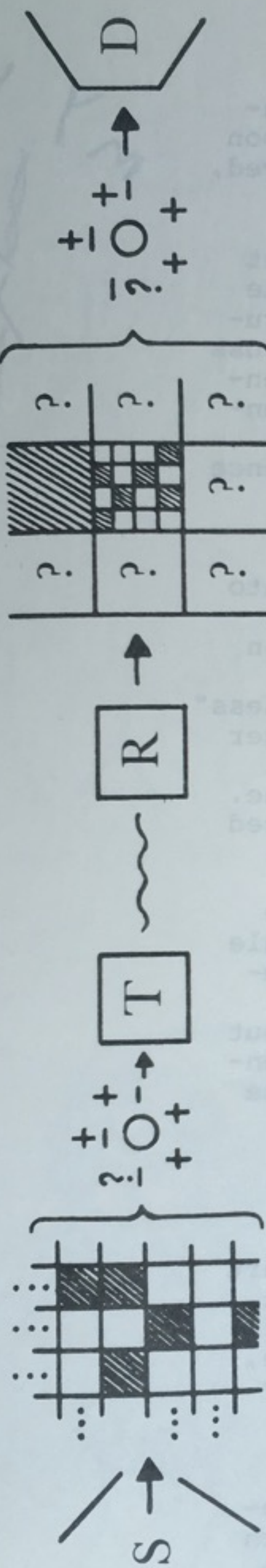
The assertion "Scott was the author of *Waverly*" is a classic instance used in discussing the role of the referring expression. What this sentence ordinarily intends is that the individual whose proper name was "Scott" is that particular individual who wrote the novel *Waverly*. It is not the case that we wish to assert that the words "Scott" and "the author of *Waverly*" have the same meaning, but rather that the individual whom we name can be identified as the person who wrote *Waverly*. Specifically, it is not the role of the expression "the author of *Waverly*" to refer. What makes a phrase a referring expression is precisely the intention of the speaker; words do not, of themselves and independent of their usage, refer. Langer makes a similar point with respect to the act of reference; reference is accomplished not by words at their own level, but by nonverbal, referring acts (such as pointing, looking, vocal inflection, and the like). Words are themselves too general in connotation and require to some degree the assignment of specific denotations.

In section 1.1, we have already noted that graphical or "presentational forms" (to employ Langer's terminology) have no referents. I can, for example, show someone a drawing I have just done of my house, and tell them it is of my house. Surely it "describes" my house and "refers" to it. But the token of communication I have just displayed is still present in its raw and immediate simplicity. It is a drawing of my house and is not the simple equivalent of my enunciating "my house" in a pure act of reference. The drawing is an instance of a nonreferential token.



Langer, Susanne, "Philosophy in a new key", Cambridge, Mass.: Harvard University Press, (1960)





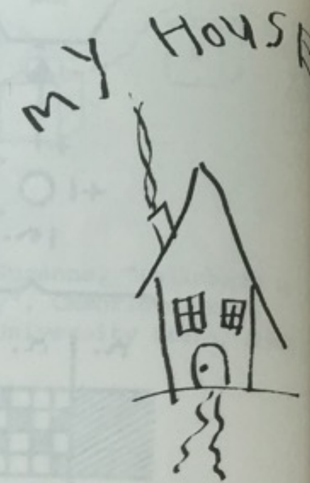
2.2.1 Nonreferential Tokens

A nonreferential token, then, is a communicative element or primitive not indicating or referring to anything beyond itself. The drawing of my house *qua* graphic is nonreferential in essence; if what I wanted to do was to refer to my house, and I were communicating graphically, I would simply write "my house," or perhaps draw some simplified stick-figure of a house and add a label, "mine." Surely, I would not labor over the icon beyond what its service as pointer or indicator would justify unless I were of an unreconstructed rococco temper.

Under certain conditions, *words*, the transparent media *par excellence*, can attain to nonreferentiality. If one were to listen for some minutes to a looped tape recording of some word recited over and over, it would not be too long before the word ceased to act as a word *pointing beyond* to a referent, but instead commended our attention at the level of its immediate sonic qualities. Then, a short time later, we might hear the word as being some entirely different word. For example, the word originally recorded as "Chaplain" may turn into "Chapping," "Champagne," and so forth. A sort of "semantic satiation" sets in, and our brain endeavors to endow the momentarily denuded referent sound pattern with an alternate, fresh referent.

2.2.2 Areferential Tokens

A drawing of one's house can be referential or become referential depending upon how it is employed. As commonly employed, it is nonreferential, that is, we deal with the drawing, rather than with the house through the drawing. (A blueprint of the house under construction is quite a different case, being a graphic instrumentality by means of which we can discuss the house.) While ordinarily nonreferential, the drawing has the inherent potential of becoming referential because it has an essential one-to-one correspondence to something beyond itself (the real house).



But now, with the mind's eye, "zoom" into some small portion of a drawing of the house, say part of the lintel. Going in so close results in the context of the graphic shard being lost; the "lintel-ness" of the icon drops away. We can no longer "identify" what the object is, but deal with it as pure surface, color, and line. The effect is somewhat like that produced by the "What-is-it?" photo-puzzles appearing in newspapers and magazines in which some common object or objects are photographed either from an unusual angle or from very far or very near. A close-up of a nail-file, for example, will appear to be a desert mountain range, but a bit too regular. We cannot quite identify the object, but run it against some procession of possibilities, finding resononance on some dimensions but not enough on others.

In such photo-puzzles, it is essential that we search for referents. It is part of our "contract" as puzzle-solver that we do so. But there is something about the brain that strives toward reference, as if our minds were designed primarily to orient us to an "outside" world. Referents are both irresistible with respect to words seen printed in our native language, and compelling with respect to the sight and sounds with which we are surrounded. The unreferentiable sense-datum is uncanny and disturbing.

Our evolutionary legacy of hunting (and perhaps being hunted) compells us to "account" for any stimulus, to locate its referent and determine its danger or benefit to us.

We can find instances, however, like the photo-puzzles, where nonreference occurs. We find it *fun* -- perhaps because we experience a nameless and exquisite residue of primal danger in the safety of our livingrooms. As an example, abstract paintings invite us to consider *pure* surface, *pure* texture, *pure* line. Often the same lines and shapes will appear in several renditions of a painting with red tones in one version, yellow tones in another, and blue tones in yet another. We are invited to generalize across painting to the *pure form* investing them all, but entirely for that form's sake; it is not the form *of any thing*.

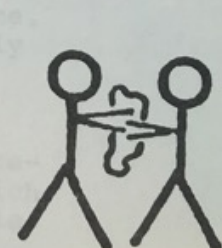
In pop art, a gigantic plastic frankfurter may confront us. The familiar form is pulled out of context nonedible and titanic in proportion) and thrust at us. Apart from any specific intent on the artist's part, we are now forced to consider the form alone, already sundered from its familiar manifestation (regular, eatable hot dogs) and returned to us as graphic hyperbole.

2.2.3 Proximities of Referent

Consider the following situation: You are at a dinner party in a foreign country. Out of politeness your hosts and their other guests converse with you and even each other in broken English. As time passes, they lapse into their own tongue among themselves, and with enough wine, maybe even with you. The point is that you are listening to and trying to understand a foreign language. We contend that if your dinner partners are discussing a referent close in both space and time -- the quality of the wine, the design of the room -- you will understand most of the transactions. Conversely, if they are discussing politics, telling a story about what happened at the beach, or engaged in a heady conversation on neo-brutalism, you will be at a loss.

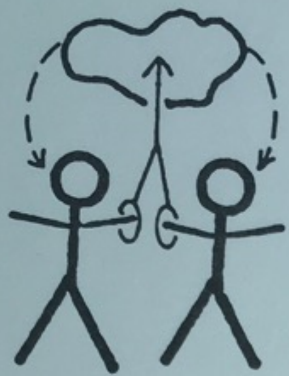
The observation is not startling. In the former case, the proximity of the referent is such that you can infer information from it and they can refer information to it (with gestures, eye movements, etc.). What is more important is the scale of proximities, the extremes and that which lies between. Dr. Avery Johnson, in an unpublished paper and in coversation, articulates five points on this scale. The adjacent diagrams are taken directly from his work.

In the first, the referent, the representation of the referent, and the conversation are all one and the same. Johnson uses the example of making love. Noticeably absent are: languages, symbols, and objects of discourse. In section 1.5.1, Through Versus With, we discussed two paradigms. This first level of proximity, what Johnson calls "immediate," is the epitomy of "with." The participant in the dialogue is the medium through which one discourses with oneself. Its "reality" is in the transformations it imposes.

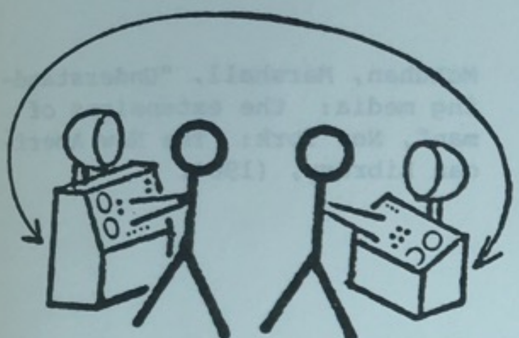


The second starts to engage graphical conversation in its approximation to strict conversation theory. A sophisticated example is found in dual cockpit controls.

While the goal is indeed to fly the plane; the referent is both close and communal. The "communal" dialogue can be vulgarized to the computer graphics (in a loose usage of the term) we find in bars, airports, and home television attachments, namely: Ping-Pong, tennis, and the like.



In the third diagram we find adjacency. Environmental controls are a good example. The referent (for instance, temperature) is close but only controlled through an intermediary machine. The control can be viewed as a policy and two protagonists bandy the policy by directly affecting the climate.



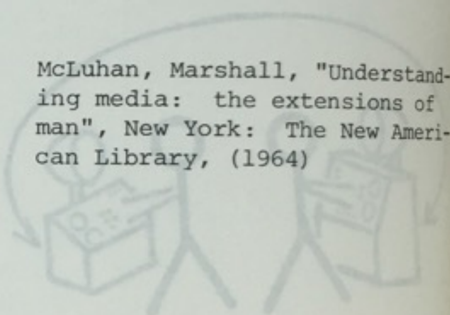
The fourth is computer graphics as we know it: metaphorical. Air traffic control is an example inasmuch as two controllers, each with their own console, are looking at the same airspace, perhaps observing different airplanes, but sharing a system of representation. The referents (the airplanes) are further away in space and time, diagrammatically represented in this case. The conversation can be viewed as the understanding of what each traffic controller presumes the other traffic controller will do. This is achieved through protocols, knowing the other controller, and sharing a common goal.

The last stage, "symbolic," is most of computer programming as we know it. The referent is far away in space (and usually time) and the syntax of interaction is inseperable from the intended meaning. The referent may even not exist except ontologically as it is referred to: that is, it may be totally symbolic of relationships and therefore be beyond physical grasp wherein an experiential sharing could take place. Appendices II, IV, and XI share a common example of sending a telegram to a Martian about Cezanne.

2.3 Proximities

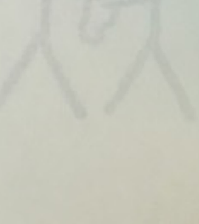
Interpersonal communication was once, in a time we can no longer even imagine, severely limited: you had to be next to someone to communicate. As you moved further away, you lost eye contact, and soon shouting would give way to hand waving. Hence the birth of media: the extensions of man. The breakthrough of the printing press forced an implicit commitment to letter-based language words and fixed sets of standardized symbols. When electronic media entered our lives in this century, bringing back a sensible response time and the capability of interchange, the concentration unfortunately remained on language: morse code, telegrams, telephones. Television brought back the visual element but without feedback of reasonable cycle time. You can play chess by mail since the interactive space is shared and the span of the game itself is long. But you certainly cannot carry on an interactive graphical conversation on commercial television. To communicate interactively and at a distance, our hands are tied and our eyes are distracting; we can only talk, grunt, hum.

McLuhan, Marshall, "Understanding media: the extensions of man", New York: The New American Library, (1964)



This proposal is a mechanism for bringing graphics back into our interpersonal relations. The lack of visual subtlety and sophistication in everyone's everyday lives is attested to by the most natural selective system in society: Madison Avenue attack schema. The concensus seems to be that only through the most intensive visual barrages can attention be gained or memory inscribed.

We want to bring back graphics to interpersonal relations because of our commitment to enhancing interactions in all modalities and graphics is particularly powerful and surprisingly neglected. Enhancement is possible in the case of two individuals in the same room (close proximity), as well as at the distance of a phone call. By understanding the limiting case of what is necessary to converse graphically at a distance, the proximate case can be clarified.



Helping two designers in separate cities work over the same cup of coffee brings a change in culture equivalent to that of the entrance of the telephone in verbal communications. This new modality, bringing in a fresh conceptual space to share at a distance, is a major increase in interpersonal relations. Scribblephone is a first step (Section 5.4.1).

Please note that this is not a plea for removing the physical proximity of individuals arbitrarily. Nothing should or will ever be the equivalent to two persons sharing the same coffee roll. The addition of new sensory modalities at a distance is a compromise, forced by the presumed necessity of individuals being in separate spaces for personal reasons. You prefer the city, your coworker cannot live anywhere but in the plains of Nevada. Other sense modalities need not be neglected: one could postulate the touch-analogue to a shared graphical space (Section 4.3). At a particular point in your conversation over the diagram in front of both of you, you wish to "punctuate" (notice the analogy from language) your point of view by nudging your partner -- so you nudge a pressure-sensitive tablet, and your partner is nudged in the arm, and your point is made with the personal interaction as if you were in the same physical space -- but not quite, and here is the central issue. We submit that given the option, physically present interaction is far preferable. This includes all those aspects of modalities that are unobserved, barely conscious, and just-a-feeling-I-had type of human interactions.

A good example for clarification is that of theater, where the interaction between actors and audience is the least definable and measurable. Postulate the choice between a real performance and a simulated one in which all modalities are perfectly reproduced, including the essential actor-audience interactive loop. We submit that in these two indistinguishable situations, the case of the actors present in the same physical space is and always will be the more valid interaction. This is a humanist view, which is maintained throughout this research.

The absolutely central philosophical point of view is that the purpose of higher degrees of interaction, and increased modalities and simultaneities, is to enhance the human needs and desires for communication. Any action in the direction of depersonalization is in clear error.

2.4 Color Reinforcement

The perception of color has always been an important ability of the human visual system, allowing identification of obmects and recognition of subtle changes from the norm. Humanity has genetically and culturally acquired a wide range of psychological reactions to various colors, including preferences, physical and conceptual associations, and psychoneurological coding of color space (e.g., perception of hue, saturation, and brightness rather than the relative red, green, and blue content of a particular color).

Color is therefore of prime importance in the coding of any visual interaction, be it alphanumeric or graphical.

1. Redundant coding: Particular objects, shapes, and other conceptually classifiable groupings (e.g., various grammatical components) can be represented by a particular color. Thus, depending on the cognitive viewing mode (search, compare, associate), the one-to-one reinforcement of parameter type with color can exploit faster or more subliminal perception mechanisms that could reduce conscious processing and intraverbalization in a task.

Lettvin, J.Y., "The colors of colored things", RLE, QPR, MIT, (1967)

2. Error detection: The perception of unexpected colors for objects normally redundantly coded in color can quickly cue an abnormal, illegal, or incorrect condition. These color misassociations can be quite prominent (pink elephants) or subtle (slight change of skin tone to reflect emotion).

3. Substitutive secondary coding: In some cases, the primary parameter or coding mechanism may be difficult or ambiguous to perceive (due, for instance, to a particular spatial configuration).

In such cases the viewer can substitute the secondary color encoding or illumination parameter to resolve the recognition conflict.

4. Nonredundant coding: This is perhaps the most important type of color coding, where the dimensions of the color variable can add information without reducing, detracting from, or even being correlated with other information since color is an extension-free variable: a point can be colored even when it is too small to have texture properties or an object shape. Thus the addition of the three dimensions (hue, saturation, brightness) of the color variable to a graphical conversation process does not compromise resolution or geometric integrity as does shape coding, cross-hatching, etc. Color increases the bandwidth of communications by increasing the information (e.g., number of entropy bits) per unit visual area.

Color has a great impact on the other senses due to the natural tendency to associate colors of visual information with colors of objects and phenomena from our past experiences. "Every color produces a distinct impression on the mind and thus addresses at once the eye and feelings," as Goethe wrote. Such reactions can be used to advantage in graphical conversation systems to convey more than just the semantic sequencing of characters and sketches.

Johann, Goethe, "Theory of colors", Cambridge, Mass.: MIT Press, (1970)

Due to environmental experiences and conditioning, the human reaction to color and the natural association of physical parameters with color varies from culture to culture as well as geographical location. Certain basic associations are quite universal in defining what could be thought of as warm colors (red, orange, yellow) and cold colors (cyan, blue, indigo). Warm colors are usually associated with the sun (direct light), and such qualities as opacity, stimulation, denseness, earthiness, nearness, heaviness (in weight), and dryness. Cold colors, on the other hand, associate with gestalt concepts of shadowiness, transparency, sedation, airiness, farness, lightness (in weight), and wetness.

In applying the results of color psychophysical measurements, human engineering experiments, and psychological tests to designing color graphical conversation reinforcement mechanisms, it should be remembered that color effects are never absolute but are relative to the total situation.

Color coding relies upon the early-instilled verbal reinforcement of visual recognition of color hues. "The powerful semantic differential is the only approach so far developed which is sophisticated enough to place color naming research on a firm basis." Thus, in addition to conscious and subliminal associations of colors and physical parameters or broader memory concepts, color scales with numerical accuracy can be created because of the uniformity of color hue recognition and accepted (or easily trained) naming conventions.

Of course, these powerful possibilities of color coding and color inference have distinct disadvantages if misapplied or incorrectly planned. Poor choices of color codes or referents can induce negative subliminal emotions that can lead to strain, fatigue, or misinterpreted communications.

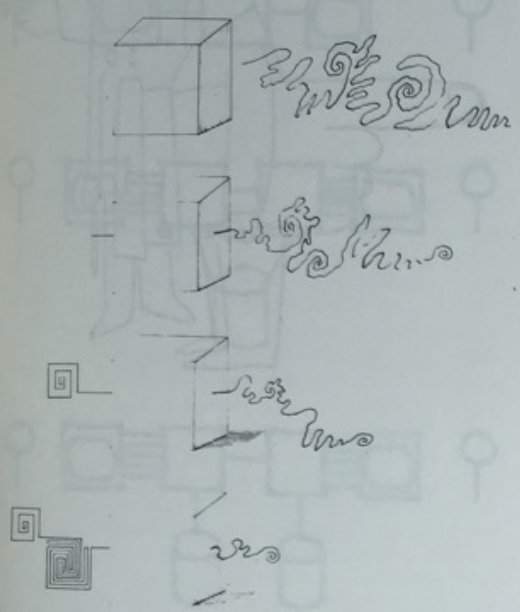
Color has another role beyond reinforcing communications in its associative and coding functions, namely to improve the communications channel. Investigators have found yellow to be representative of force, action, and repulsion, and blue to induce negation, weakness, passivity, and attraction. Other studies have tried to relate the color of a child's instructional material and learning environment to performance (one study found orange to be the best color). Other researchers have long appreciated the impact of the dominating colors in an object, surrounding, or field of view and the physical and mental health of the viewer. "It is now ... apparent that physical health may be impaired by color surroundings -- mostly by response to changing moods."

In summary, the uses of color in interpersonal and intrapersonal graphical communications systems are quite varied, ranging from the three-dimensional extension-free coding properties (e.g., hue naming) to the much more subtle subconscious or nonverbal level processes of identifying, classifying, and associating and even to the induction of feeling in the other senses.

Johannes, Itten, "Kunst der farbe", O. Maier, Pavensburg, Germany, (1961)

3.0 MEDIATION

3.0 MEDIATION



Mediation is an essential ingredient of successful communication. This chapter elaborates upon that conviction through examples and by outlining the factors necessary for successful mediation. The sections then review our experience in these areas and point to our intentions for the proposed work.

Mediation is making certain the point "gets across." It is the intent behind the plea, "Do what I mean, not what I say." It is accomplished by:

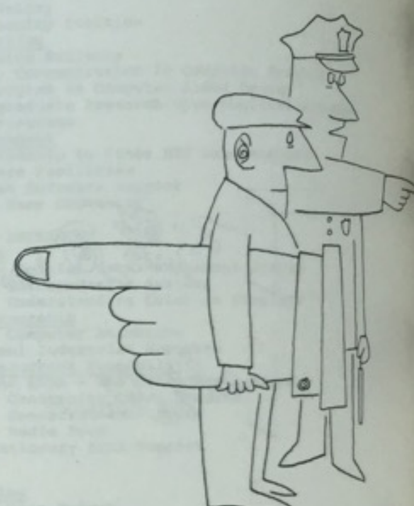
1. Amplifying - adding more information, perhaps to set a context
2. Reducing - eliminating redundant or confusing information
3. Focusing - drawing one's attention to a central issue
4. Translating - phrasing the intentions of one party in the idioms of the other.

Examples of mediation are ubiquitous. Everyone has used the phrase, "He doesn't speak my language," in reference to someone who fails to use common metaphors. Such dilemmas are often resolved by a third, mediating party. Even the critic's role is that of mediation -- deciphering a message encoded in one modality and recanting it in terms less opaque (to some).

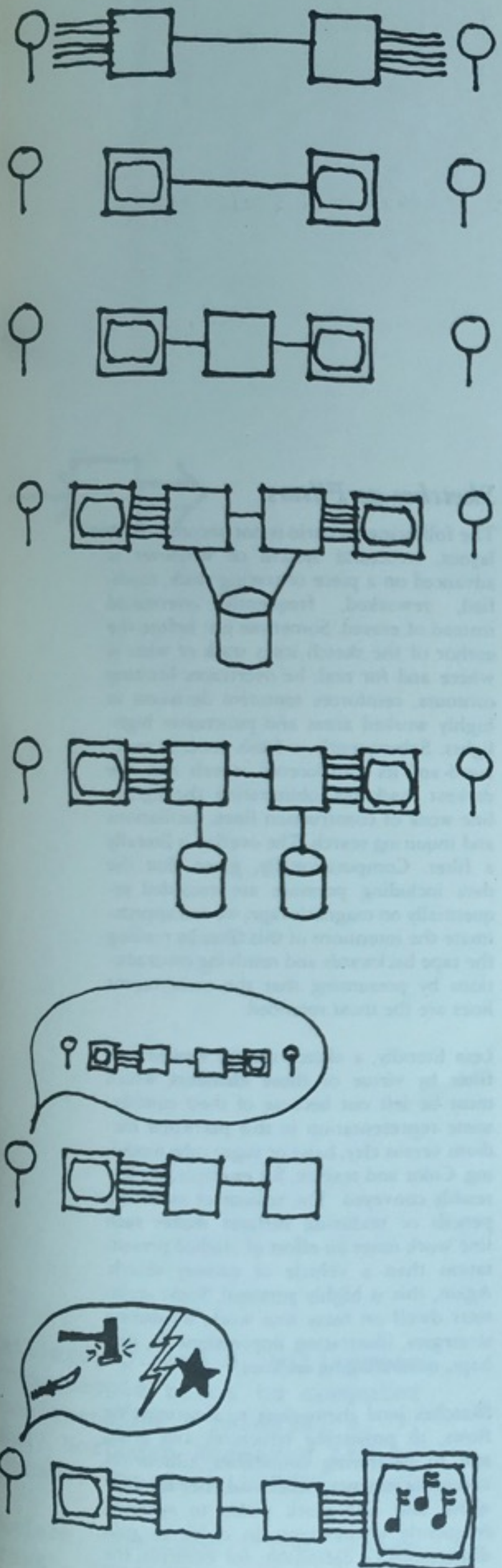
The need for translation is not mitigated by the use of graphical languages. Witness the case of the architect who has spent a lifetime refining graphical shorthands (plan projections, detail sections) in an attempt to convey spatial concepts to clients who perceive only by means of the least abstract of representations (perspectives, photographs). The machine should mediate, allowing the architect to "speak" graphic shorthand and enabling the client to "listen" to a more representational message.

Nor is mediation confined to interpersonal communication. How often must people puzzle over obscurely scribbled notes and diagrams -- "What was that all about?" Imagine the power of these notes self-elaborating as one frowned over them.

What, then, are the requirements for a good mediator? Mediation requires a knowledge of the parties involved in a conversation and of the topic being discussed. Knowledge of the parties (personalization) is necessary to know what message is intended ("When George says 'left,' he means 'right'") and to know how best to insure its proper reception ("Turn to starboard"). Knowledge of the subject is necessary to make the proper transition.



Sections 3.2 and 3.3 address issues pertaining to the knowledge of the conversants by reviewing our philosophy and experience in the areas of personalization and inference making. Knowledge of topic is discussed in section 1.5, Intelligent Systems; additional threads of that issue are further explored in section 3.4, Memory.



3.1 Filtering

We use the word "filtering" in an active sense to mean adding and transforming information as well as subtracting it so that the intended meaning is conveyed with the least amount of extraneous and confusing information.

An appropriate paradigm is that of a skilled and efficient secretary who handles routine business, screens and interprets incoming information, and expands outgoing information, occasionally writing an entire letter on the basis of a few phrases.

In a computer-mediated interpersonal conversation, the filtering operation may give the appearance that the two parties are engaged in different conversation; the images viewed at either end need not be identical at all times. Depending on the level of inference making and personalization, the conversation will fall somewhere on the following spectrum:

1. Sharing the same images
2. Instantaneously transformed images
3. Personalized interpretations of shared models
4. Interpretations of personalized models

Stages 3 and 4 eliminate the requirement of concurrency for purely discursive information. Each user, in interaction with his own machine, develops a model (the entailment mesh of subsection 1.5.2) that then serves as a basis for the conversation.

Either party may ask questions, emphasize points, or cause some aspect of the model to be transmitted.

The control of such actions may ultimately reside in the machine, such that the person at the other end would not know if he were talking to a person or a machine -- a graphical version of the "Turing test."

The timeliness and appropriateness of the filtering operations are the key to their success. As the inference-making capacities of the system increase, this issue will have important implications for diplomacy and privacy, knowing to whom one's computer may reveal one's feelings and who should receive a tactful interpretation.

The following subsections describe four aspects of filtering:

Amplifying
reducing
focusing, and
translating.

Although the themes of this section inform all of the tasks described in chapter 5, they find their most specific application in subsection 5.3.14, Transformations.

Sketches as Filters

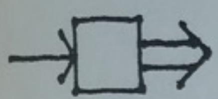
The following scenario is not uncommon. A layout, structural system or whatever is advanced on a piece of tracing stock, modified, reworked, frequently overtraced instead of erased. Sometime just before the author of the sketch loses track of what is where and for real, he overtraces limiting contours, reinforces tentative decisions in highly worked areas and punctuates highlights. Subsequently, a fresh sheet is overlayed- and its translucency reveals only the darkest markings, obliterating the lighter line work of construction lines, vacillations and inquiring search. The overlay is literally a filter. Computationally, given that the data including pressure are recorded sequentially on magnetic tape, we can approximate the intentions of this filter by reading the tape backwards and resolving contradictions by presuming that the most recent lines are the most intended.

Less literally, a sketch can be viewed as a filter by virtue of those elements which must be left out because of their cumbersome representation in this particular medium versus clay, balsa or sugar cube modeling. Color and texture, for example, are less readily conveyed. The tedium of switching pencils or texturing surfaces makes such line work more an effort of studied presentation than a vehicle of cursory search. Again, this is highly personal. Some architects dwell on fussy line work, incubating strategies, illustrating impressions or, perhaps, camouflaging realities.

Sketches lend themselves to diagramming flows, to projecting structures and grids, and to delimiting boundaries, silhouettes and containments. Otherwise, they are awkward, and line work yields to symbols, frequently annotations, in order to gain dimensions of definition; for example, the label "brick" may substitute for what otherwise would require undue graphic detail.

3.1.1 Amplifying

One of the most aggravating aspect of using a computer is the requirement that every request be described in specific and detailed terms. The novice finds this disconcerting, eventually discovering that the machine does not really know what he *means*, and the expert finds it annoying, having to type (or digitize) many things in order to accomplish something he could describe to another person in a few words because of the other person's grasp of the context of the description.



The role of amplification is to add information. This can happen both on input to the machine and on output from it. A common form of input amplification is the abbreviation facility provided by many time-sharing systems for command input. A logical extension to graphics is the interpretation of gestures (subsection 5.3.4). Such features can go beyond mere expansion of macros, interpreting the user's actions in the context of the situation, the data currently displayed, and models of the user and the problem area.

Amplification is also the expansion of output to make it more meaningful to the user. In its most banal form, output amplification can be the selection of brief or verbose system messages, based on the machine's perception of the user's familiarity with the system.

Analogies drawn from the data base can be especially useful in output amplification, extending the grain to provide a more detailed graphical representation. This may be in connection with a specific message ("turn left on 10th Street" becomes a map of the intersection including representations of landmarks best known to the recipient) or may be a means of exploring a highly structured and complex message. This last idea is best illustrated by Ted Nelson's Hypertext concept, in which a user manipulates himself through a completely cross-

Millard, G. and H. Williamson, "How people react to computer conferencing", Telesis, 4, 7, Bell Northern Research Ltd., Ottawa, Canada, (1976)

Nelson, Theordor, "The hypertext", Proceedings World Documentation Federation, (1965)

indexed text file, explicitly controlling the level of detail and the sequence of reading the message.

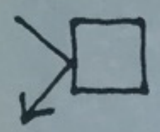
Amplification may result in the expansion of a previously reduced (subsection 3.1.2, Reducing) piece of information, causing it to be transformed. This process is described in more detail in subsection 3.1.4, Transforming.

Another application of amplifying is the reiteration of something that was not understood, as a teacher does in response to the bewildered stares of students.

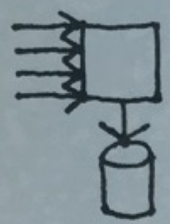
Amplification also includes the possibility of adding information that is relevant only to the man-machine interaction itself. This might take the form of offering possibly interesting information during those periods when the user is not actively engaged with the machine. Contemporary examples are to be found in the various messages and pictures displayed on the "free" terminals of many time-sharing systems.

"Multics programmer's manual, reference guide", Honeywell Information Systems, (1975)

3.1.2 Reducing

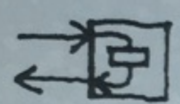


In a future marked by inexpensive, high bandwidth communication and instant access to information, much of it computer generated, there will be a pressing need for a facility to cut out the superfluous. Information to be filtered may be:

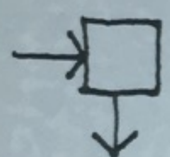


Irrelevant
Redundant
Annoying
False
Misleading

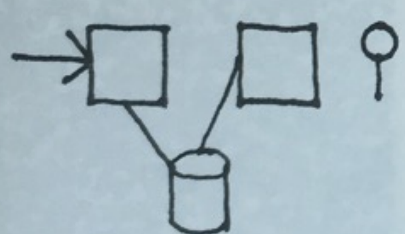
The action to be taken can be modeled on the operation of the office staff of many public offical s who receive a large volume of correspondence:

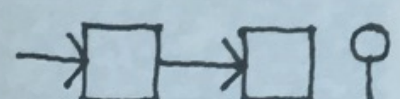


Ignore
Note for summaries
Respond
Forward
Save
Interrupt



These actions are tied to a model of what the user knows and wants to know. Incoming messages are classified on the basis of content (subsection 5.3.6, Caricature) and origin. The first reduction processes will be simple passive filters, as in the Stanford wire service extractions. Eventually, as the computer mediator assumes those functions the user does not wish to perform, surrogate conversations will be possible.





3.1.3 Focusing

We use "focusing" to mean those techniques by which the user's attention can be directed. This can happen in two ways:

1. Obscuring irrelevant information by simplifying the display
2. Calling attention to relevant information by elaborating the display

Although these two operations may each result in a net change in the quntity of information being displayed, they are distinguished from adding and reducing by their action at a different level of transparency. Adding and reducing operate at the level of the subject matter itself and thus affect its *cognition*. Focusing affects the *perception* of the information; it is a means by which the subject matter can be viewed. At times this can result in a complete change of the image, as when the focusing knob of a powerful microscope is turned, bringing different levels of the slide into focus.

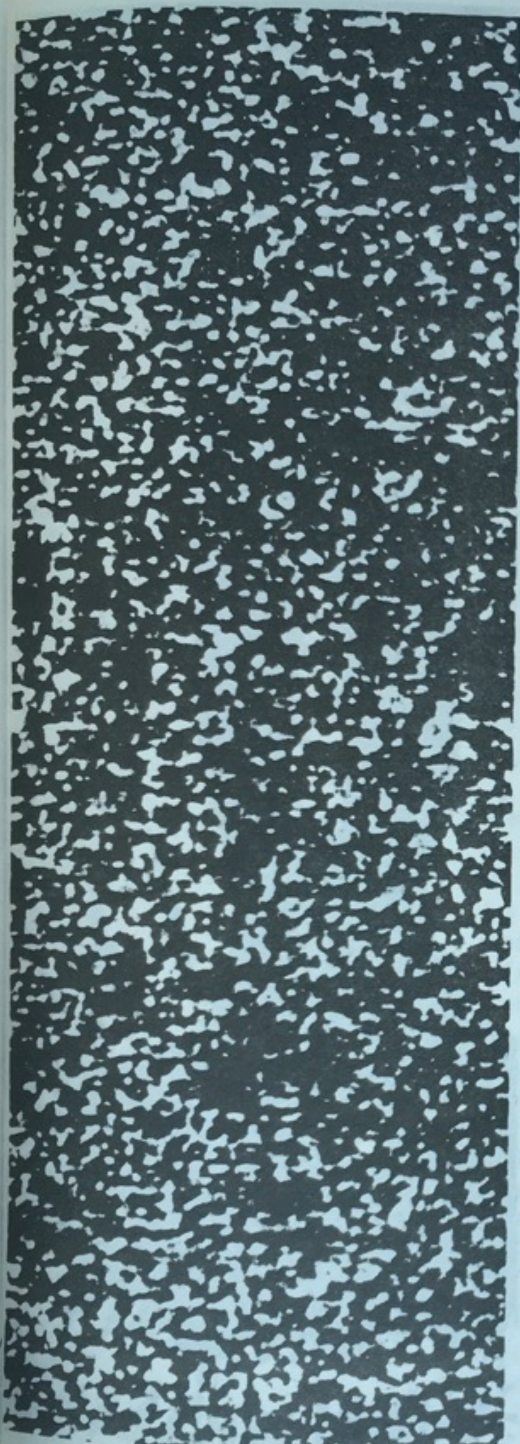
Obscuring irrelevant information may be performed by

1. Blurring, diffusing, bleeding
2. Diluting and darkening
3. Texturing
4. Abstracting

Blurring, diffusing, and bleeding are techniques by which information at each point in the image is caused to overlap with its neighboring points. The algorithm can be chosen to simulate any one of a number of physical process, from turning the focus knob on a camera to sprinkling water on a madras print.

Diluting and darkening result from reductions of the saturation and intensity, respectively. As such, they involve global modifications to the picture rather than the local effects of blurring.

Texturing is the adding of information, as



by screening, which masks information in the original picture.

Abstracting is an all-inclusive category. The above three categories all result in a degree of abstraction as they cause details of an image to be lost. It is easy to imagine any of the above operations transforming an irregular brick wall to a brick wall, then a wall, then a rectangle, then nothing. Unfortunately such transformations can not separate essential from inessential information. The wall not only becomes more abstract, it becomes harder to see at all as the outline blurs along with the detail. Only an active filter, such as an artist or a computer can selectively focus an image. An approach to this problem is discussed in subsection 5.3.6, Caricature.

Calling attention to relevant information is more than just the inverse of the above. The obscuring techniques act to reduce the attention-getting properties of details in an image, such as sharpness, distinctness, contrast, and visibility. Similarly, new dimensions can be added to an image. They are:

- Sound
- Color
- Texture
- Motion
- Alternation
- Visual effects

The use of sound as a positioning clue is an important part of our current work in spatial organization of data and is described in subsection 8.1.1, ARPA -- Spatial Data Management System and in Appendix III, Multiple-media Man-Machine Interaction.

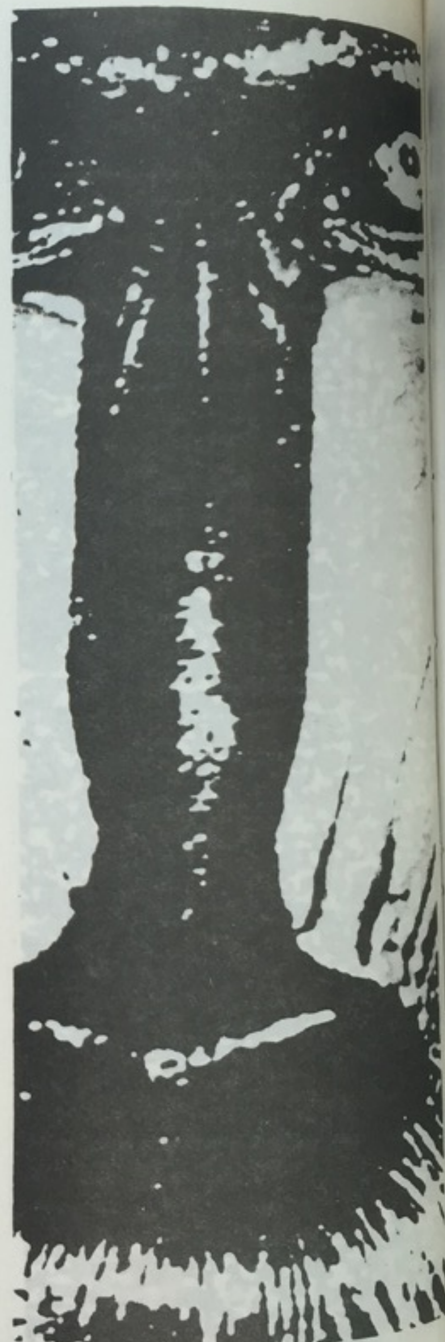
Color and texture can be added selectively for emphasis just as they can be subtracted generally for de-emphasis. While they both find application throughout chapter 5.0, Tasks, color is addressed specifically in subsection 5.3.7, Color Adjuncts.

Motion, alternation (blinking), and visual effects in general can be used to attract attention. The beneficial effects of motion and alternation on cursor performance are well known and are explored in subsection 5.3.5, Cursors. Other effects, inspired by broadcast industry tools such as chroma-key may find widespread application as raster scan displays become commonplace.

The differences between obscuring and calling attention to can be likened to the differences between the cinema (or television) and the theater. In a stage production, the attention of the audience is focused primarily through attention-getting mechanisms such as sound, motion, and lighting. Films, on the other hand, choose a much more restricted point of view, eliminating much of the setting, and restricting what can be seen in a frame by selective focus. This use of focus is so common-place that its absense can be quite striking, as in the deep-focus scenes of *Citizen Kane*.

Dynamic computer graphics has typically followed the cinematic paradigm, but with the added capability that the user may choose the "camera angle" and focus. Unlike the filmmaker, however, the computer user has no perspective of the scene other than the viewpoint he chooses for his imaginary camera. As users of three-dimensional display systems can testify, it is very easy to get lost with such a restricted point of view.

The advent of large-screen computer displays will open the option of theater-like rather than cinema-like perspectives. In such an environment, the focusing capabilities described in this subsection will assume significance.



3.1.4 Translating

The three preceding subsections described ways that a message can be transformed. Information can be added and subtracted, and parts of it can be emphasized and de-emphasized. In this section we extend the concept of filtering to include the replacement of information as it passes through the system. This translation process enables two people (or two viewpoints embodied in one individual) to communicate in the language and style that best suits them.

An architect can sketch a diagram of a building. The machine can then translate the diagram into a rendering of the building for a client to examine. Alternatively, the architect may view the same output for the purpose of evaluating the aesthetic features of the design.

The ultimate applications of translation, personalization, and inference making, will allow each person to speak and draw in his own vernacular and be completely understood (or as understood as he wishes to be). In the meantime, translation of graphics should prove easier than translation of natural language, as explicated in section 1.4, Characteristics of Graphical Conversations.

An early application will be the translation of gestures, where meaningful results can be achieved with simple one-to-one mappings.

The transformations described in subsection 1.4.7, Tautological Transformation, and further explored in subsection 5.3.14, Transformations, can be employed to give two people two different perspectives on a concept.

The ability to infer and express intent is the key to bringing the computer-mediated transaction up to the level of communication currently available only by using human intermediaries (see section 3.3, Inference Making).

The increasingly sophisticated levels of translation imply underlying data representations of growing complexity. The one-to-one translation of gestures will probably not make use of any internal canonical format, but the addition of context to such interpretations will require a representation of the progress of the conversation.

Eventually there will be many levels of data base with intervening mappings. A typical gesture may be translated through the following representations:

Gesture of person A
Drawing of person A
Data base of person A
Canonical data base
Data base of person B
Drawing of person B
Focus of person B

3.2 Personalization

Appendix VII recounts a story about a psychotic painter undergoing therapy. The analyst spends years with the artist, whose illness happens to worsen. The anecdote ends with a situation where the painter's figures have degenerated into scribbles recognizable only by the doctor. This is the limiting, and pathological, case of personalization. Milder examples are found in interpersonal relations with travel agents, waiters, and the like. Intrapersonal interaction is characterized by personalized management of one's desk, calendar, wardrobe, and so on.

Personalization is a very complex social phenomenon that we do not intend to study as such. Specific tasks in chapter 5.0 will dwell on levels of personalization that range from the trivial (Is the user right- or left-handed?) to the nontrivial (Is the user a wholist or serial thinker?). Our current Office of Naval Research work (subsection 8.1.2) concentrates on this topic in particular; we are offering it as a subtheme in this proposal to NSF, to be read as an attitude rather than as a task.

For the most part, personalization is absent from computer graphics. Even the commonplace profiles of time sharing do not invade the format of displays, input technologies, or graphical shorthands that might be available. In section 4.3, we will call one approach to the introduction of personalization the both/and attitude and strategy.

Architecture offers a good exemplar in the design of homes. Everybody's home is personalized to some degree, even if with rented furniture. The scattering of memorabilia (or lack of them), the cleanliness, the color schemes, and the density of knicknacks are all part of personal life styles, but very much at the surface. Most people can transport this level of personalization from a brownstone to a high-rise to a ranch house. At greater structural depth (in the more literal sense of structure) one can imagine a design that is truly personalized (Appendix X) in the lack of closets, limited bathrooms, huge kitchen, windowless bedroom, etc. This is troublesome in that the hardware is static, difficult to resell, and frequently subject to outgrowing and obsolescence.

A computer analogue can overcome the above limitations because its nature is determined by software and thus is not static. In a scheme for mediation with one's self or between one's self and others, the dynamism of personalization can allow the fulfillment of the seemingly whimsical "I feel like reading it in Times Roman today." Personalization, not to be confused with sloppiness, is extremely important in making work and play synonymous. Many of the authors reviewed in Appendix VII dwell on personalization as the literal intersection of work and play. In all cases they argue for personalization in terms of the capacity to act in a creative climate. We argue that the key is in inference making.

3.3 Inference Making

Appendix II uses the following husband wife scenario:

> *Okay, where did you hide it?*
> *Hide what?*
> *You know.*
> *Where do you think?*
> *Oh!*

We believe that personalization is a necessary condition for inference making. Without personalization one has what is commonly called an assumption. In computer jargon, we contend that an assumption is most closely approximated by the infamous default option.

The Architecture Machine Group has a long history of inference making strategies for graphical conversation. Appendices V and VIII dwell on sketch recognition. Inasmuch as the recognition of sketches is not outlined as a specific task or theme for this proposed continuation of our work in computer graphics, this section will use it later as an example of one level of inference making.

A particularly human phenomenon is the desire to say something once. A particularly computer phenomenon is the need to say the same thing over and over again, to degrees even beyond those encountered in discourse with the most stubborn, dimwitted child. The simplest kind of inference making is therefore characterized as expanding macros. These are both knowledge based and personal; acronyms are an example. As a personal example, this author, non-German speaking, finds it difficult to look at a German headline with the German word for "with" and not read it as "Massachusetts Institute of Technology." Or, in another example, Marvin Minsky characterizes *Larousse Gastronomique* as having unexpandable macros: "cook until done," "use proper sauce," "spice appropriately."

Inferences are macro-expansions only at the most superficial level. In a deeper sense, an inference is the recognition of an intention, namely, what I mean versus what I say. In sketch recognition we have based this level of inference making on the speed and pressure of drawing. In the well-known adjacent diagram, the two figures are the same in shape, viewed after the fact. However, their constructions were dramatically different. The first was hastily generated, intending to imply closure, even squareness. The second, in contrast, was a carefully scribed blob, meant to be such, i.e., splined. The crux of our current NSF work is the correlation of speed to intention and its variance across individuals. Individuals vary from each other dramatically and must be "profiled" or personalized accordingly. Also, the same individual varies from day to day, mood to mood, subject matter to subject matter; thus, the system must (for the time being) be interactive (as suggested by Herot) and not omniscent (as presupposed by Taggart).

The deepest level of inference making is that proverbial target that always seems to be the same distance away no matter how far we travel toward it. That is: What do I intend to achieve? In sketching, linework tends to be a solution to an intention, which, if differently understood, might have a better solution. The way a problem is stated often occludes the nature of the problem, and frustrates the solution. One is reminded of a number of design solutions proposed to reduce crime (namely rape) in elevators of high-rise tenement buildings. Solutions included changing the layout of access or installing television cameras, alarms, and patrols. The real intention, however, was only recognized by the designer who implemented the successful solution of placing bulletin boards by the elevators at each floor. Rapidly these bulletin boards became filled with local notices (for sale, baby-sitting needed, swap parking spaces,

Herot, Christopher, "Graphical input through machine recognition of sketches", Proceedings Third Conference on Computer Graphics - SIGGRAPH, Philadelphia, (1976)

Taggert, James, "Sketching, an informal dialogue between designer and computer", in "Computer aids to design and architecture", N. Negroponte (ed.), New York: Petrocelli/Charter, (1975)

need roommate, etc.) such that a passenger-to-be could pretend to be reading the notices should the elevator arrive with a single suspect character.

3.4 Memory

This section is about memory as something more than storage. The following two subsections dwell on two particular aspects of memory germane to the dynamism of graphics. Appendix I covers its rapport to conversations stricter than those introduced in subsection 3.4.1. In these introductory paragraphs we comment on some of the static features of pencil-and-paper type memory.

A recent (winter 1975) internal memorandum at the Rand Corporation semi-jokingly warned about throwing away the message with the medium, appropos to the importance of paper in office automation (expanded upon in Appendix III). Observations ranged from the facility for scribbling notes to the ability to recognize how well read a document might be by the degree to which it was crumpled. The detective work can go further: Are their coffee stains or Campari stains? Was it folded to be put in a pocket? Was it retrieved from the trash?

This is static memory, interpretable by an observer, but not manipulable from within the medium by, for example, the author of the document. It is nonetheless an important and frequently overlooked kind of memory. The explicit and implicit marks we make on things are very personal and important kinds of memory. One need only be reminded of the common occurrence of having something (seemingly unrelated to the conversation at hand) pop into one's head and hastily jotted down in order to be remembered and tended to later.

Sketches as Memory

Sketches afford an eclectic medium for short- and long-term memory. Consider: first, how easy it is to memorize a stream of text (poem, perhaps) and recite it faithfully in comparison to how hard it is to recreate a graphics accurately without instrumentation or tracing; second, how selective a sketch is in representing only a portion of the topological and geometrical properties of a design as a result of either deliberate reduction or genuine unknowing. Memory fuzziness can be seen as consonant with design development, gaining crispness over time, developing consistently and analogous to the passage from a 6B to a 6H pencil representation. This can and ought to be true for both machine and designer.

A problem of correspondence arises between the machine's internal representation, culled from inference, and the user's representation of line work residing on paper. Remember that the experimental conditions are computationally passive. Frequently, either several geometric constructs must be brought forth by the computer as candidate interpretations or else memory must be organized with room for approximations and redundancies.

The issue of commensurate memories is complicated by the technical problem of cumulative and round-off errors. It is most visible in the problem of latching. The standard solution is to present graphic interpretations on a television-like device, forcing the user to employ the machine's memory only, that is to retreat from the use of paper. While there is certainly a future in that vernacular of conceptualization, tube instead of tablet, it is currently a limiting way of working, cluttered by the clumsiness of so-called light pens, unattuned to 6B thought. Recall that the machine's graphic inferences are not made for the purposes of straightening crooked lines or neatening sloppy drawings, but for the purpose of compressing the data into a format manageable by a participating machine. Too frequently this is forgotten, especially because we tend to show off or verify our computer programs by peeking into their memory.

The human use of the sketch as memory is more complex. This is partly because the sketch can be either a proposition or an analogy and partly because the user intuits and recalls information which, though he might claim is in the sketch, in fact is not, but is rather in his personal response to it. It is computationally messy. It is most conveniently viewed as a filtering system.

3.4.1 Derivability

When a touch typist is asked where the "P" key is located on the keyboard, he or she will neither engage in an "ASDF" exercise nor squint to visualize the keyboard, but instead will feign to type a "P" (in fact, by literally lifting hands to an imaginary typewriter). Similarly, in finding things on one's desk or in one's files, it is noticeably easier to locate something if one put it there oneself, than if one just knows where it ought to be. In short, motor involvements are important dimensions of memory, studied extensively in other contexts by Held and his colleagues. We consider these as examples of the "derivables" in conversation theory.

Held, R. and H. Mikaelian, "Motor-sensory feedback versus need in adaptation to rearrangement", Perceptual and Motor Skills, 18, (1964), p. 685

In computer graphics one finds the existence of similar derivables in the structured display list. A difficult general concept to introduce to a student already well versed in drawing and drafting is the notion of structure in drawings, even in strictly 2-D settings. The idea of a subroutine is not difficult; one can liken this to rubber stamping or any trick of repetition. But the topology of a drawing is exceptionally hard to comprehend until you have written a computer program to engage in *interactive* graphics.

Plotter or storage tube-based graphics takes derivability to the extreme inasmuch as no picture memory need be kept in line. In fact, it is not uncommon in present-day drafting systems for the process to regenerate the entire "window" (and in some cases the entire picture) to find the closest line or to point to some X-Y graphical input.

In raster scan graphics, which is where we believe the future lies, the interplay is different and less well understood. A specific task is enumerated in subsection 5.3.2, Shape-Oriented Graphics Language. Part of the newness to the problem is specifically related to memory, inasmuch as memory and the picture can be literally synonymous. In some future displays (subsections 5.4.4 and 5.4.5), the display medium itself can be readable and writeable memory (this is particularly true with thin film transistor technologies). What happens in these cases?

Derivability, or encoding, becomes a complex technical problem as well as a complex conversational space. This is aggravated by the fact that we loose precedents from which to gather enough evidence to make good starts. For example, we don't normally converse in color, and we have few examples of painting photographs. One must begin thinking about the 2-D surface as a 3-D memory.

3.4.2 The Interrupt

Early work (1968) on URBAN5 engaged in a problem area that has not been addressed since: the interrupt. In those days, the argument for dynamic memory was based on the interrupt calling to the user's attention a so-called conflict, a state of inconsistency he or she might not otherwise notice or query. The interrupt surfaced with an insidious buzz and printed messages of what the user had said and what conditions then prevailed. The unstudied problem was one of timeliness.

Appendix VII pursues timeliness in the context of creativity, within the consensus that suspending judgment is often the key to sprouting new ideas. We shall not repeat it here. Tasks in chapter 5.0 focus more on the problem of timeliness in the sense of hints, reminders, and what might be called "graphical imperatives." The mediating system is behaving like an intelligent alarm clock.

Negroponte, N., "URBAN5 - a machine that discusses urban design", in "Emerging Methods in Design and Planning", Gary Moore (ed.), Cambridge, Mass.: MIT Press, (1970)

"And how are we feeling this morning? Reply when you hear a beep."

4.0 TECHNIQUES AND METHODS

4.0 TECHNIQUES AND METHODS

This chapter is as much about styles of and attitudes toward research as it is about technologies and methodologies. The four sections that follow should be read as the givens of our *approach* to conversation theory, as distinguished from the *facilities* enumerated in chapter 6.0. In some cases these givens are mechanical devices, such as personal computers. In some cases, they are as vague as a mental set such as "both/and."

Conspicuous by omission is the notion of applications. Conversational domains are defined by applications to, for example, engineering design, office automation, and map making. If we liken our proposed research to current research on machine understanding of natural language (written or uttered), this omission would be a serious mistake. However, we remind the reader of talking *through* a machine and the consequent ability to be independent of application in basic research.

Nonetheless, the seventeen tasks listed in the following chapter will be tested in specific settings. In some cases these are specified by the nature of more mission-oriented concurrent research and in some cases these are circumstantial, as a result of the makings of our user community.

We are in the School of Architecture and Planning which includes a growing Arts Program. The fabric of users, thus has an uncommonly sophisticated and well-formed need for color graphics. This comes from both the mapping needs of planning and the video-graphics needs of the arts. We recognize that much of our current effort on color is determined by this intersection of needs and offer this as an example of applications infusing technologies with a momentum of user needs, without which the exercise is abstract and academic.

This is not to say that all the tasks will deploy techniques and methods of circumstance. Continuations of architecture-by-yourself, problems of graphical composition, and spatial data management are applications upon which we can *depend*. These are itemized in chapter 8.0.

We introduce this chapter on techniques and methods with a section on personal computers. Customarily this would find a place in "facilities" or "machine configuration." We include it here because of the conviction that "personal computers" are a conceptual change in two ways. First we can presume extremely high bandwidths of interaction. Second, we can look toward vast markets of home computers, far in advance of current games. In fact, the entry of the hobbyist into the computer market will have an enormous impact in the next five years.

The next section on shared graphical spaces is also a methodology. Consider what happened to the Picturephone. It epitomizes nonshared space; its failure as a product can be traced to this in part (though it may be more convenient to blame bandwidth). In the Picturephone scenario, I see the other party and the other party sees me or, if I push the appropriate buttons, I can see me (the intention was to allow for things like hair-combing and posing, before transmitting oneself to the other party). Never can I see me and the other user, an experiment that deserves serious attention, an experiment that underlies our entire proposal in graphical space.

This leads directly into the both/and paradigm. It is included for the reader to recognize an uncramped style of research. Some of the both/and-ness comes from interdisciplinary activities in our laboratory. Some of it comes from the composition of disparate backgrounds enumerated in the Introduction, and some comes right out of the literature on creativity: industrial, scientific, an

Koestler, Arthur, "The act of creation", New York: Macmillan Press, (1964)

artist motivations. In all of these areas of what Koestler calls *The Act of Creation*, we find agreement in suspending judgment, which is much of what both/and is about.

This chapter concludes with graphics brought back into the programming processes. Unlike the fable of the shoemaker's son going barefoot, we postulate that graphical conversation finds application in the realization of itself. One is reminded of the rarity of manufacturers of automated drafting systems using their own systems to do their own drafting.

4.1 Personal Computers

The Architecture Machine, written in 1968, is about personal computers. Our prediction that time sharing would evolve into a noncost-effective mode of computing has proved true. Current drops in processor and memory costs have made the personal computer a reality.

Negroponte, N., "The architecture machine", Cambridge, Mass.: MIT Press, (1970)

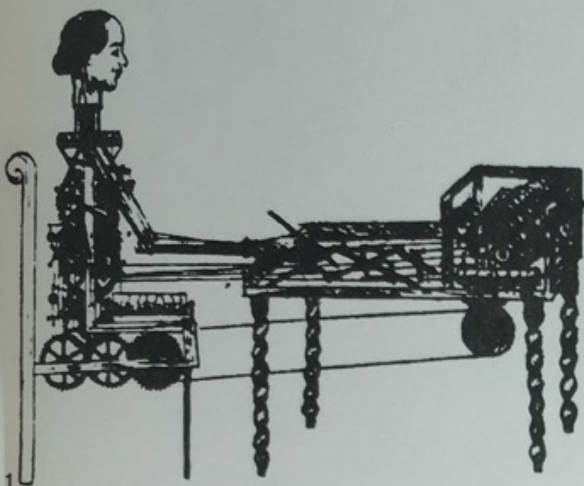
This section underscores the mini-computer-based techniques and methods that have and will continue to pervade our style and content of research. Whereas some authors argue that the personal computer is like having your own dedicated time-sharing system, we argue that the personal computer is critical to super high bandwidths between user and machine. The diagrams on the cover of this proposal purposely indicate substantive bandwidths in person-to-machine communication, but with smaller links between machines. Pervious subsections in section 3.1, Filtering, justify this within graphical conversation theory.

Shared data is critical and in many cases the actual data is entered and updated from geographically disparate locations. Consequently, we are not implying that networks or central data machines are not justified. Similarly, we are not implying that time sharing is unjustified. However, the "clients" of time-sharing systems in the near future may turn out to be machines, not people.

People will use local computing systems with large memories by today's standards. It is irrelevant to worry about their naming: micro, mini, or maxi. What will be important to our methods and techniques is the following list of four general requirements:

1. High-level languages. This is not the place to argue LISP, as in the Artificial Intelligence Laboratory's LISP machine or something like PL/I on our current Interdatas. Suffice it

to say that the notion of a personal computer is an empty exercise if one must deal with assembly languages and impotent operating systems similar to those that prevailed from 1970 to 1975.

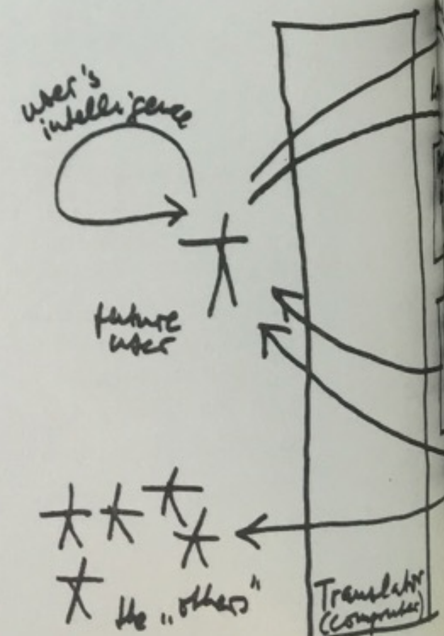


2. Large address space. The sixteen-bit address space is unduly limiting. The dropping cost of memory will make practical the use of systems employing interactive programs of large size. A large address space is an important force controlling the methods and techniques used to explore high-bandwidth communication.

3. High-memory bandwidth. A lot of memory is not sufficient; it must be fast and probably multiported. In raster scan graphics, we find the thresholds of memory speed interfering with seemingly simple transformations.

4. High-speed firmware. This last requirement for the personal computer results from our experience with writeable control store in a computer graphics environment. Certain operations require algorithms complex enough and reused enough to warrant microcode implementation, but not ubiquitous enough to warrant being imbedded in the machine's repertoire. This is discussed in section 5.4, Hardware Landmarks.

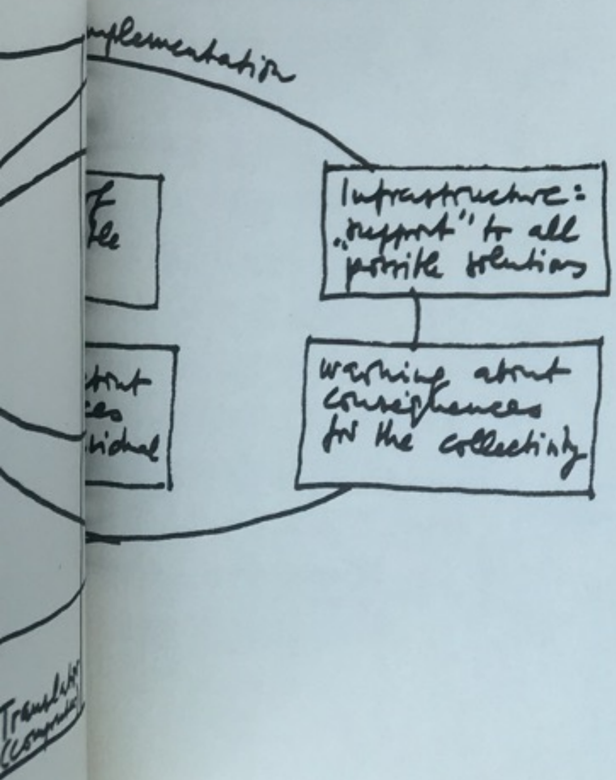
A final note on the personal computer strategy regards our future in terms of specific hardware (namely Interdata's next wave of 32-bit machines) and our position with regard to MIT's Laboratory for Computer Science (LCS, which is discussed in greater detail in subsection 7.3.1). LCS is embarking on a personal computer project hand-in-hand with industry. Our plans are to be part of this development with respect to conversational paradigms. Study of our current machine configuration (subsection 7.3.2) reveals a file processor capable of talking to a variety of personal computers, not just Interdatas.



4.2 Shared Graphical Spaces

A central component of any conversation is a space shared by both parties. The notion of shared space is derived primarily from experience with the built environment. The size, shape, level of activity, and background noise all enter into perception and thus affect one's conversations in the space. The projects and themes of chapter 5.0 are conceived as the elements needed to construct a graphical space that can be shared, forming a framework in which graphical conversations can be studied. The two concepts are perforce intertwined. Our study of graphical conversations, and the growth of the attendant body of theory, will be an important aspect of the knowledge of shared graphical spaces.

An important property of a shared space is that the actions of each individual are felt by both parties. Shared spaces can be created electronically as well as physically, the telephone being a common example. As a shared space, the telephone provides more than just a high-speed word transmission medium. The nonverbal utterances, background noises, and even the sound of a handset being set down on a table all contribute to the sense of presence essential in perceiving an interaction as a conversation. Similarly, a shared graphical space must be more than just a surrogate paper. It must convey a sense that another sentient being is involved in the process. Possible means of achieving that goal range from clues on the whereabouts of the other party's pen when not actively drawing to the holographic projection of the other party, bringing a replica of that person into the same room.



The proposed research is applicable to a broad spectrum of hardware. While most of the tasks are applicable to a small CRT and tablet, we envision the creation of a shared space that is also a space in the physical and cognitive sense, such that the perception of the space includes not only an imaginary world behind the screen but the physical space in front of the screen and the cognitive space existing in the minds of the conversants.

4.3 Both/And Versus Either/Or

We have all been told that we cannot have our cake and eat it too. This maxim, however, has only contextual truth. It accounts for visions being cut short and either/or decisions being made too soon. In a research environment, it is necessary to explore many alternatives rather than make an a priori decision. Such exploration can often lead to a solution superior to any of the original options. This section alludes to a process of natural selection as well as a process of choice through personal preference. Both force the researcher to march forward with a both/and attitude.

A plethora of studies exist that evaluate the light pen over the data tablet as an effective form of graphical input. These studies have measured hand strain, hand-eye dislocations, learning curves, and the like. The results of the studies have two general failings: (1) They are based on statistical and normative measures that occlude important idiosyncrasies and stylistic differences. (2) They presuppose that an either/or decision is necessary in the first place.

The both/and policy is truly an attitude. It should not be read as a recommendation that industry should flood the market with unmanageable multiplicities (yet). Frequently, propriety is gained through natural emergence of "bestness." Let us illustrate by the example of a light pen on a calligraphic display.

Light pens are in general hideous devices. They are usually fat. They cannot see "blackness." In cases where a tracking cross is used, the tracking cross tends to be a slippery, computing sink. Nonetheless, light pens are reasonable pointing devices (the French almost called them *doight*, "finger") since they do return the proper and telling line no matter where you point on the line. (Even here there is some argument about end conditions if the display processor is very fast.) But even the interrupt in the display list can be emulated with a hardware comparitor; hence, why a light pen? Because it is on the same surface as the display.

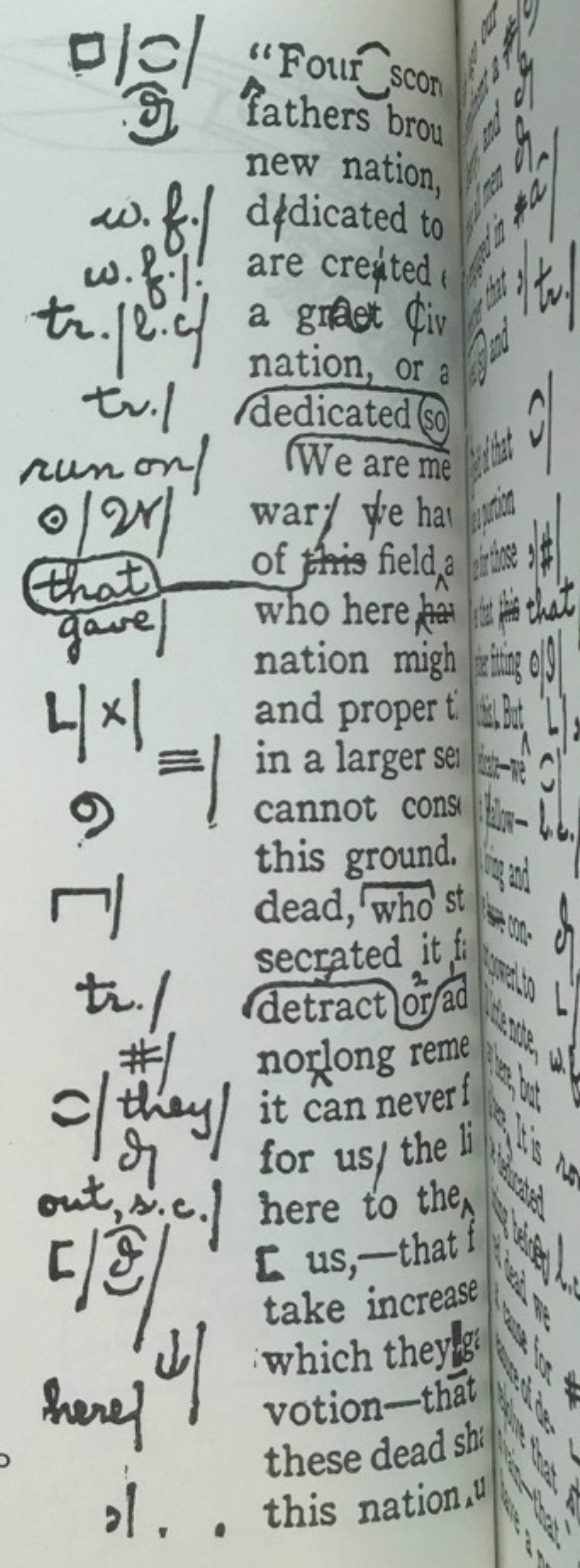
Our example of the both/and approach lies in the use of fingers (see Appendix IX) as light pen alternates. We postulate that the finger can do anything that a light pen can do and better (especially if we recall the aid of a tracking cross or cursor for occasions where the stubbiness of one's finger obscures the detail to which one is pointing). The advantage is so obvious. Just consider the convenience of moving from typewriter keyboard to display without having to pick up a gadget.

The point is that a study of fingers versus light pens is unnecessary. The technology of one outstrips the other to the point where evaluation becomes unnecessary. Should cost emerge, then trade-offs are in order. However, we have selected an example where the costs are presently the same.

Much of this commentary results from recent dealings with ARPA (see subsection 8.1.1 and Appendix III). Being better is not sufficient. Being much better is a requirement. To this end, we frequently do "both" of something.

The other reason for both is precisely the recognition of idiosyncratic behaviors. What is good for one person is not necessarily good for another.

A site visit to the Architecture Machine would reveal this both/and attitude. Chapter 6.0 concentrates on evaluation techniques and testing plans in a formal experimental psychology setting. This section has been placed before chapter 5.0, Tasks, in order to share the flavor of our approach and propel the reader into our research agenda without intellectual parsimony. This attitude is dramatically strengthened by MIT's internal policies, the Undergraduate Research Opportunities Program (UROP).


“Four score
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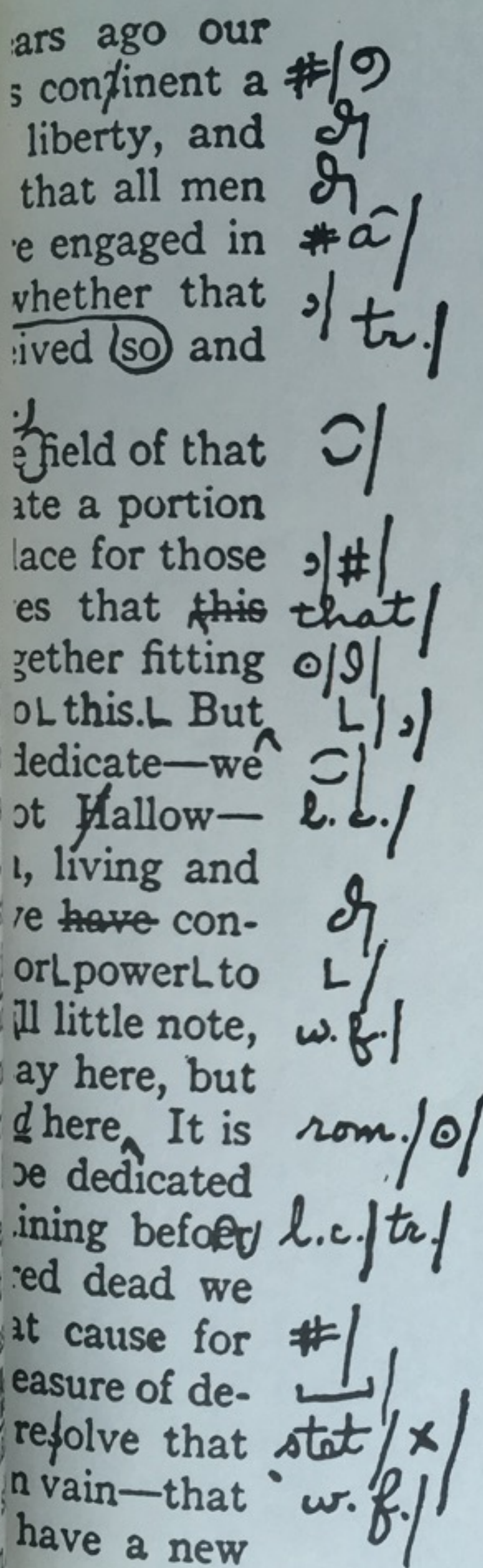


4.4 Graphics as a Programming Space

Most programs are written by programmers, people who sit down with a computer and edit, compile, and debug programs that are then used to draw inferences, tetrahedrons, or perform the application at hand. These operations are not truly graphical because the basic operations are linear rather than spatial. Modest attempts have been made to use the higher bandwidth and interactivity of the spatial domain, such as the introduction of "real time" editors and other such systems programs, but these attempts represent exceptions to the rule.

If the person writing the program does not think of interaction with the computer as spatial, an extra barrier against thinking graphically about the application program's problem space is created. This lack of familiarity leads to rather dull busy-box graphics that often hinders the user of the program. Having the basic computer system present a spatial facade would provide an environment in which good interactive software could be written.

Programming is a highly linear and precise action. A program may not function if a single number, which can have thousands of possible values, is off by even one. This information can best be transmitted by means of text positioned on the screen because the information, pivotal to the programmer, is relatively limited in quantity, but it must be represented symbolically since the required resolution is finer than can be perceived spatially.

Understanding a program as a whole can be incredibly difficult to do without some way of "zooming out" on the program and looking for global patterns of reference and execution rather than individual statements. Introducing the system to a novice can be aided immeasurably by such tools. A more experienced programmer could use the tools to fine-tune the execution of the program and to detect major changes in its usual behavior patterns. For example, frequently used sections of code could be represented more intensely than relatively unused sections as an aid in detecting bottlenecks. Differentiating recently executed code from code executed earlier by varying screen intensity can be used to study program flow and program locality, which is often difficult to get a handle on.

As a design philosophy, graphics support must be high on the list of basic operating system functions. It must not be treated as an arcane additional feature lest it fall into disuse. In such a "graphical operating system" the applications programmer manipulates objects in the application's domain, leaving the transformation to displayed images to the screen.

By its visual nature graphics can be used to increase the degree of interaction between man and machine in many ways and at many resolutions. To take full advantage of these features offered by hardware, software must make it as simple to "talk about" graphics as to manipulate the data itself. This is a large part of making graphics the programmer's way of life.

5.0 TASKS

5.0 TASKS

This chapter is divided into a review of current tasks, an examination of seventeen projects and themes, a discussion of seven hardware landmarks, and plans for dissemination of results. We ask that this not be read as an a la carte research menu, but as a complete package. At the same time, we are not proposing a single (1982) system.

The tasks we have elected to propose as specific efforts result from three observable situations:

1. Interactive systems still do not provide much of the immediacy and facility of pencil and paper methods.

2. Current and ongoing projects in our laboratory have had specific spin-offs and show promise that points to a new future (section 5.1).

3. Seemingly obvious techniques for dialogue have not been studied because start-up costs are too high to warrant or risk the research.

Consequently, many of the tasks have tacit assumptions about what <u>we</u> feel <u>we</u> can do. Additionally, there is the implicit assumption that our work will continue to get formal and informal industrial support (section 8.2). This not only lowers the costs (through hardware donations, for example), but disseminates and incorporates ideas and inventions in time frames far shorter than those of journal or book publication.

In many regards, the value of a task can be measured in terms of its extensibility. We offer the rule of thumb for thesis size. That portion of an idea seeded by NSF should be considered on the scale between an M.S. and Ph.D. thesis. (This would mean between 15 and 20 theses during the five year period proposed.)

Finally, we want to remind the reader that concurrent, mission-oriented research is feeding basic studies with applications, informal evaluation, and intellectual resources.

5.1 Review

This section is situated within "Tasks" in order to synopsize how current work projects into the future, as discussed in the Appendices. We will try to identify those areas of research that fell short of our expectations at the beginning of our current three-year NSF grant. In most cases these hinged around implementing personalization, particularly personalized design systems. Achievement beyond our expectations (of March 1973) has been in the general area of interaction and the specific area of video-based graphics. It is no wonder that these pervade section 5.3 and that we are exhibiting caution and theoretical retrenching (with the important and specific help of Dr. Gordon Pask) in the application of artificial intelligence techniques to knowlege of the user.

Some of the projects in progress will continue into the first year of this proposal as extensions and links to what we are calling a graphical conversation.

The following is the abstract that accompanied our 1973 proposal:

> *This is a three-year proposal to design, build, and test a class of machines, both hard and soft, that can deal with the properties of incompleteness, contradiction, and vagueness, properties which are characteristic of any design behavior. Our goals are:*
>
> *to augment design abilities,*
>
> *to recognize design intentions, and*
>
> *to generate design solutions*
>
> *in a fashion that affords people the opportunity to be as inventive and creative as possible.*
>
> *Our assumption is that so-called computer-aided design does not exist. People do not design with machines. Rather, designs*

are done off-line, on the backs of envelopes. They are done in concert with other people, discussing, frequently arguing. The design process is inherently partitioned from the machine by the limited channels of communication between human and machine, and by the technical barriers to having computers recognize and infer human intentions. Our proposal consists of four families of objectives to expand these channels, to overcome these barriers and then to apply these techniques. Broadly titled, the four families of objectives are:

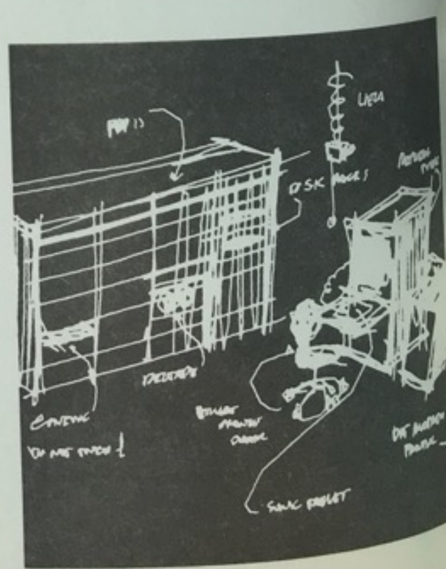
1 *graphical input techniques*

2 *complex descriptions and displays*

3 *personalized design systems*

4 *architecture by yourself*

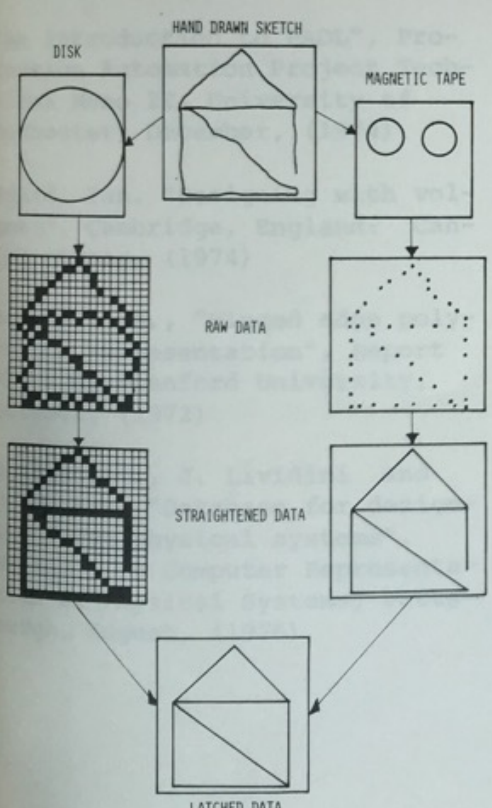
A rigorous program of validation and dissemination of results also plays an integral part of this proposal.



5.1.1 Graphical Input Techniques

We submit that one of the most serious impediments to interactive graphics is the awkwardness of input. We also submit that we have come a long way toward recognizing sketches. This is extensively reported in Appendices IV, V and VIII. What is not reported and remains unexpanded is the theme: beyond the stylus. From one point of view this is what we will call "the intelligent pen," giving it logical ink and a knowledgeable eye. From another standpoint, this means the expansion into gestures, tactile input, and inputting with one's eyes.

Sketching holds a low profile in this document because we believe that it is done as a data compression task and it has shown immediate relevance and applicability to such things as Scribblephone (5.4.1) where two users need to share the same graphical space over low bandwidths. We look forward to demonstrating this on two Scribblephones by June 1977 (depending on Bell Northern).



The key to the projection of graphical input into the future has two sides: knowledge-based input and interactive input. Knowledge-based input is currently embodied in "super-project" (accent on the last syllable), a project (accent on the first) to include manufacturing knowledge in the input vernacular. For example, in parts programming, if you know a piece will be milled versus cast, you have allowable geometries within a well-formed set of degrees of freedom (up to, let's say, a five axis NC milling machine). More importantly, in input, one should be able to request a bevel or chamfer instead of truncated or adding volumes.

Interaction playing a serious role (it is not that we do not have confidence that we can recognize the drawing and hence need the user to be explicit). Fingers are an important expansion in in the theme of "interaction," initiated by our current NSF work and picked up by ARPA (summer 1976) as a real medium for command and control.

To date, however, we have failed to achieve multiple finger input. While this problem is part of Gestures (5.3.4) we mention it here as a specific example of extending our current level of effort, with a first-year conceptual jump into "rear-view" techniques (so-called peek-a-boo tube CRT with transparent phosphor). The scheme is simply to look head-on (head-in) at fingers, rather than try to determine activity on a plane while observing that plane as an edge. This is a specific example of ongoing input work that will find extension into graphical conversations though not enumearted as a composite theme in section 5.3. Note that a "rear-view" approach will afford recognizing area input (like a palm holding down something), which conceptually projects our current line-and-point input jargon into a much richer realm.

5.1.2 Complex Descriptions and Displays

This work is about the qualitative differences associated with complexity, in contrast to the quantitative differences. There are many design systems (Applicon, Computervision, Gerber, and so on) currently suffering from quantitative leaps (from the 1.4 megabyte world up to 300 megabytes that have not been accompanied by any qualitative or conceptual change. In most instances faster CPV's, floating point hardware, and high bandwidth mass storage have served as the only vehicles for change. One of the reasons for having a Computervision system in our laboratory, as we do, is to bench mark against an industry standard for complexity.

The most notable compromise in our current work is the lack of data-base design in what we called in our March 1973 proposal "qualitative scaling" and "nonlinear representations." Also we have elected not to compete with the important work at Carnegie-Mellon and Sanford Universities.

Our work has found momentum beyond our wildest expectations of 1973 in the area of complex displays. This is not in the sense of Hank Christiansen's excellent extensions to older Utah efforts. Instead, it is in the sense of real-time, video-based, interactive graphics.

The beginnings are illustrated by a program called "PAINT." In this program the user is given the opportunity to use his cursor as a:

1 Boundary maker
2 Flooding device
3 Pattern Generator
4 Function generator

Each of these actions is associated with modes or menus extending the range of "painting" enormously. Detailed descriptions and documentation is in progress,

Christiansen, Hank, "Pressure patterns: forced vibration of a submerged sonar transducer", Computer Science Division, University of Utah, (1975)

"An introduction to PADL", Production Automation Project Technical Memo 22, University of Rochester, December, (1974)

Braid, Ian, "Designing with volumes", Cambridge, England: Cantab Press, (1974)

Baumgart, B., "Winged edge polyhedron representation", Report AIM-179, Stanford University, October, (1972)

Eastman, C., J. Lividini and D. Stoker, "Database for designing large physical systems", Workshop on Computer Representation of Physical Systems, Pittsburgh, August, (1976)

and beyond the scope of this subsection. You will note that four of the seventeen projects listed in the schedule are first cousins with the innovations in PAINT. These include some features not yet implemented, but forthcoming (before the termination of our current NSF grant). For example: (1) intermixing fonts; (2) cut-and-paste photographs; and (3) levels of transparency, are being designed at this time. Subsections 5.3.2, Shape-Oriented Graphics; 5.3.7, Color Adjuncts; 5.3.8, Sound-sync Computer Animation; and 5.3.16, Painting Photographs, are examples of direct extrapolations.

5.1.3 Color Studies

Problems currently being studied by the color researchers at the Architecture Machine Group could be extended to graphical conversation. Color-coding systems are being developed that exploit the three-dimensional properties of colors and the ways in which these colors are interpreted by the brain as hue, saturation, and brightness loci according to three parameters, such as population, income bracket, and zoning. Thus the power of color as a unique sensation (pink to represent the conjunction of dense population, low income, and factory zoning) may also be separately interpretable as red to mean dense population, desaturated to code low income, and high intensity to signify factory zoning.

We would like to incorporate these first efforts into the graphical conversation motif discussed throughout this proposal which naturally divides into three classes of paradigms:

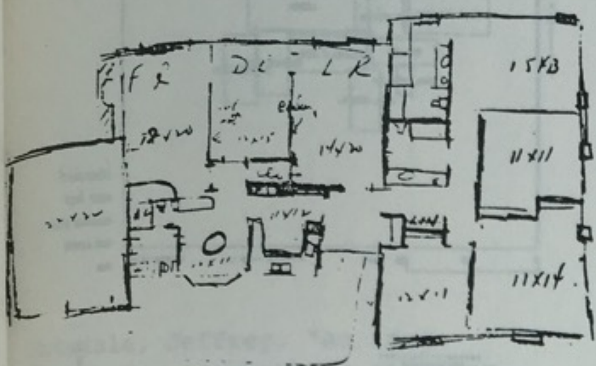
1. Two people are communicating via a graphical system over a distance large enough so that the only information that passes between them is through the system. At times their communication is facilitated by proximity of their referent (see subsection 2.2.3), but in any case it will be enhanced by color coding for emphasis and for feeling. That his coding is natural is indicated by common linguistic associations of emotions with color (e.g., "seeing red," "black mood," "brown study," "blue"). The "distance" in this paradigm may be metaphorical: Graphical conversation serves the same purpose when the conversers do not share a language, when one is deaf or agnosic, or when one has a speech impediment or is aphasic.

2. Two people are controlling a referent in real time, and the only way they know the status of their referent is via their separate graphical displays. An example is two air traffic controlers with separate radar screens, each controlling an air plane. In this case, urgency or an intensive physical attribute of the referent may readily be communicated in color. Also, the controllers can communicate with each other via the coded color of the referents they control.

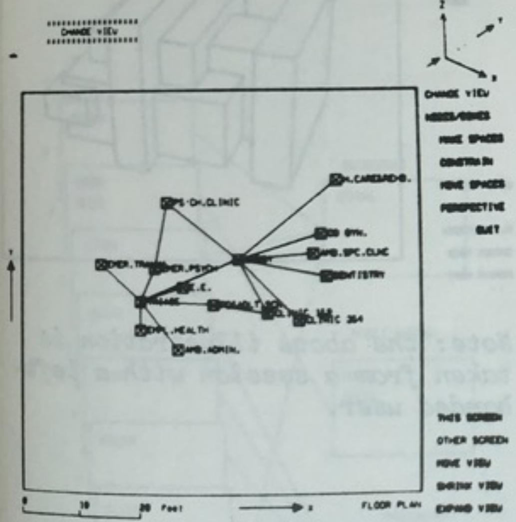
3. One person has control over many interacting referents, which are represented on a graphical display. Once again, urgency or an intensive physical property of the referent can be coded in color.

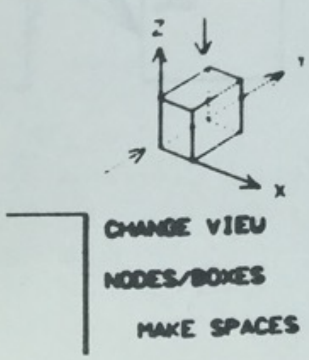
Color coding may help in these situations by adding to one's speed of judgement, by enhancing the meaning of an involved message, by reducing the fatigue incurred in interpreting a message, or simply by rendering a communication more "human." The specific projects we plan in this area are discussed in subsection 5.3.7.

Another current project attempts to relate the properties of color vision studied psychophysically and neuroanatomically to the concepts of aesthetics and preference as expressed by artists and lay people. Studies in the areas of human engineering and gestalt psychology have come up with a number of specific results that have not been tied in at all with the lower level, highly quantitative studies of the other two fields.



Owner/Designer's Sketch of House Plan





5.1.4 Applications

The application-independent nature of this proposal is a response to the disappearance of the NSF office for "Applications in Research" within computer science. As stated in the introductory paragraphs of Chapter 4.0, Techniques and Methods, we must remain tied to applications enough to sort out the "realities" of a computer-mediated conversation.

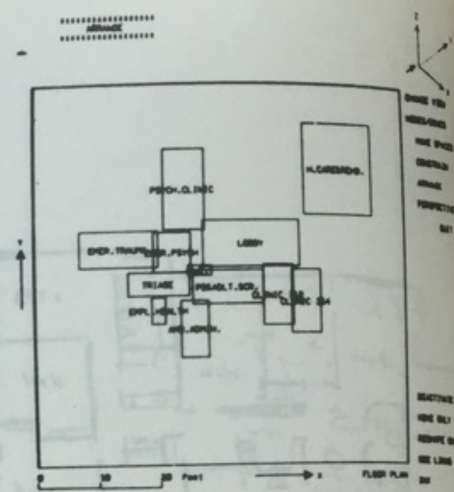
Currently, our applications concentrate on architectural design. Most of our work has been in architecture-by-yourself, reported in Appendix X and discussed in Appendix VII in connection with amplifying creativity. Other work has been in multi-layered space allocation (particularly in the thesis of Masanori Nagashima) and grammars (Alfonso Govello and Mike Gerszo, working on M. Arch., M.S., and Ph.D. theses, respectively).

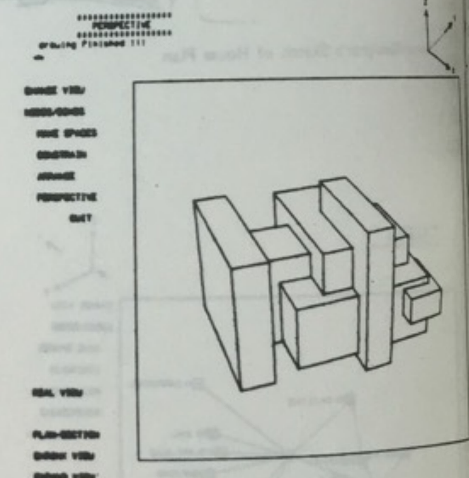
These specific applications will find support outside the scope of this proposal. However, they will affect our work and have affected our methods by engaging in applications that demand the highest standards of comfort, smoothness, and resilience at the interface.

Special attention should be given to the work of Masanori Nagashima (MAS). although limited in scope and size to that of a thesis, it has great extensibility and potentiality. In some regards, it is the closest we know to intrapersonal communication in CAD. This is due to two distinguishing features: (1) multiple and simultaneous representations, and (2) continual machine manipulation.

The user of MAS enjoys the advantage of two displays, either of which can present plans and sections, perspectives, or diagrams. Additionally, the user is aided by a well-formed key, particularized to the representation.

More germane to interaction is the constant massaging of data by the machine. Adjacent illustrations cannot share the constant sense of elasticity and dynamism portrayed in the surfacing of background tasks such as energy estimation, constraint resolution, or simple rapportage. Suffice it to say that the user's sense of engagement is enhanced by something quite different from the usual back-and-forth command-driven enterprise.





Note: the above illustration is taken from a session with a left-handed user.

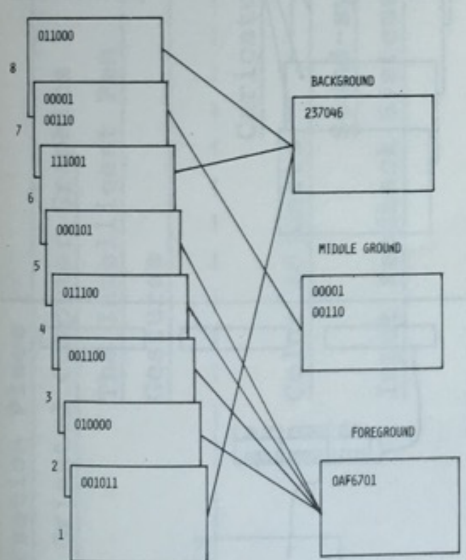
5.1.5 Hardware

Moderate effort has been invested in the design of new hardware. More often than not, the acutal development has been externally funded. Aside from the usual interfacing of new devices or small hardware modifications, we have embarked on three serious efforts, listed here because of their impact on our current methods and our proposed work:

1. Raster scan display
2. Multi-processor network
3. Color hardcopy

Entwisle, Jeffrey, "An image processing approach to computer graphics", in Abstracts of Conference on Computer Graphics and Interactive Techniques, Boulder, Colo., July, (1974)

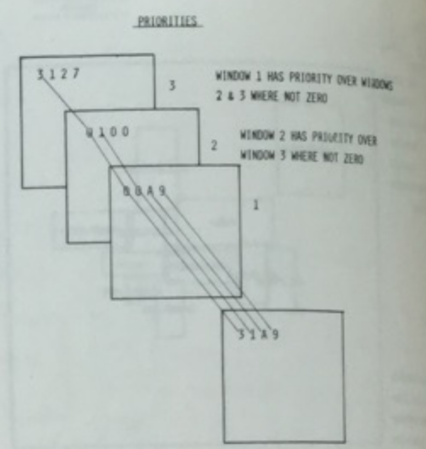
Our so-called 85 is one of the first frame buffers built, first published by J. Entwhistle. Appendix VI describes the lessons we have learned from its dintinguishing and not-so-distinguishing features. It was built around the Interdata model 85 that has writeable control store, but alas, is a 16-bit machine (section 4.1, Personal Computers). It has allowed for many of the developments in color theory and digital video discussed previously. A Ramtek 9300 has been recently acquired to relive some of the traffic currently on the 85. Our and Ramtek's future is in 1000-line color (subsectin 5.4.3).

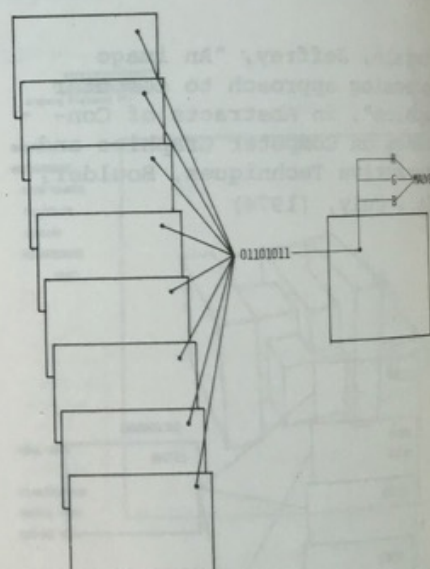


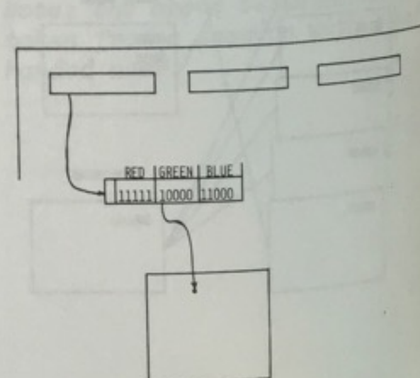
"Mulitple Mini's" was the theme of the 1973 NCC meeting at which we first presented our shared bus implementation of more than one processor having access to each peripheral. This sharing is either on the per-sitting basis (as in a terminal), the minute-to-minute basis (as in a high-speed printer), or the millisecond-to-millisecond basis (as in a disk).

A new scheme is in progress to revamp the shared bus and, more importantly, relieve it of the high-speed record-oriented devices. The new system will run with a file processor powerful enough to unburden the user's processor and operating system of all file manggement tasks.

Finally mention is made of color hard copy. This is primarily in connection with the 85, funded in part by Xerox. The hardware attack on the problem was motivated by the conspicuous absence of modestly priced color graphics, namely, the uses of softcopy, were continually impaired by the inability to cost effectively extract hardcopy representations from the computer. The thesis of Lawrence Stewart addressed this issue with enough insight and perseverance to invent a method for frame-buffer scrolling.







5.2 Schedule

	1977-1978	1978-1979	1979-1980	1980-1981	1981- 1982
5.3.1	Conversation Place				
5.3.2	Shape Oriented Computer Graphics				
5.3.3		The Intelligent Pen			
5.3.4		Gestures			
5.3.5	Cursors				
5.3.6			Caricature		
5.3.7		Color Adjuncts			
5.3.8			Sound-sync Animation		
5.3.9		Input Feedback Systems			
5.3.10				Drawing with Your Eyes	
5.3.11	Seeing through Your Hands				
5.3.12	Knowledge Based Graphics				
5.3.13			Measuring Interaction		
5.3.14			Transformations		
5.3.15	Tracing Paper				
5.3.16			Painting Photographs		
5.3.17	Personalizing the Screen				
5.4.1	Scribblephone				
5.4.2		Touch Sensing			
5.4.3		1000 Line Color			
5.4.4	Frame Buffers				
5.4.5			Flat Displays		
5.4.6			Write-Once Memory		
5.4.7	Color Hardcopy				

5.3 Projects and Themes

The following seventeen subsections outline new work. Our discomfort with the idea of distinguishing a project from a theme is manifest by their being freely intermixed. As a consequence, some of the following subsections have well-formed starts and stops, hardware and software schedules, and a closely coupled computer architecture. Others, meanwhile, are device-independent objectives that find specific instrumentation and experimentation in a dozen different settings, across more than one task.

Brainstorming sessions at the onset of writing this document lead to a longer list, which has been shortened and limited to those we feel we have a unique ability to pursue. Pursuits in 3-D real time animation, data structure design, picture encoding and transmission, simulated realism (a la Utah), and direct 3-D output are noticeably and purposely left out.

5.3.1 Conversation Place

A conversation place is a room in which every wall is a display, every surface is a tablet, and voice and sound permeate 3-space. It introduces the itemization of our tasks because it is the only project which traverses all five years and which already has an initiation by IBM's interest in a media room (subsection 8.2.1) and ARPA's contract (subsection 8.1.1) to study the feasability of a spatial data management system.

Subsection 5.4.5 (Flat Displays) dwells on forthcoming technologies. In this task we are willing to live with one wall (7 foot by 10 foot), rear projected, for the first three years. The idea is to combine sound in 3-space with large scale graphics, distinguished from current systems by the new role of peripheral vision in the human system. Present-day TV projection (even 1000 line) is not sufficient to achieve striking, close-up, detail, but is sufficient to explore large-screen graphics and parallax-free graphical input as a media for graphical conversation.

Appendix III has a section on screen size versus theme size. It's author, Richard Bolt, parallels the viewing of *Gone with the Wind* on a 19" monitor (which many Americans did on November 7th and 8th) to many of the present-day computer graphic displays. A visit to Washington's new NASA Museum (a recommendation made to us by Dr. Craig Fields of ARPA's Cybernetic Technology Office) revealed the five-story high, 70 mm presentation on flying, an extreme of screen size that is so captivating that it may be one of the few examples where the surrogate is better than the real thing.

Although foolhardy to presume that kind of size and resolution in the short term, this subsection postulates that it is time to prepare for it. There is a paucity of theoretical work on the topic of large-scale interactive graphics. As the title of this subsection suggests, such a scale causes the sense of screen to become a sense of place (even forgetting our introductory premise of walls that literally surround).

Leading questions for this task are:

1. In proximity to a large screen, how does the structure of the display attract the attention of the user's foveal vision when necessary?

2. What are the programming and interaction consequences of knowing exactly where the user is looking?

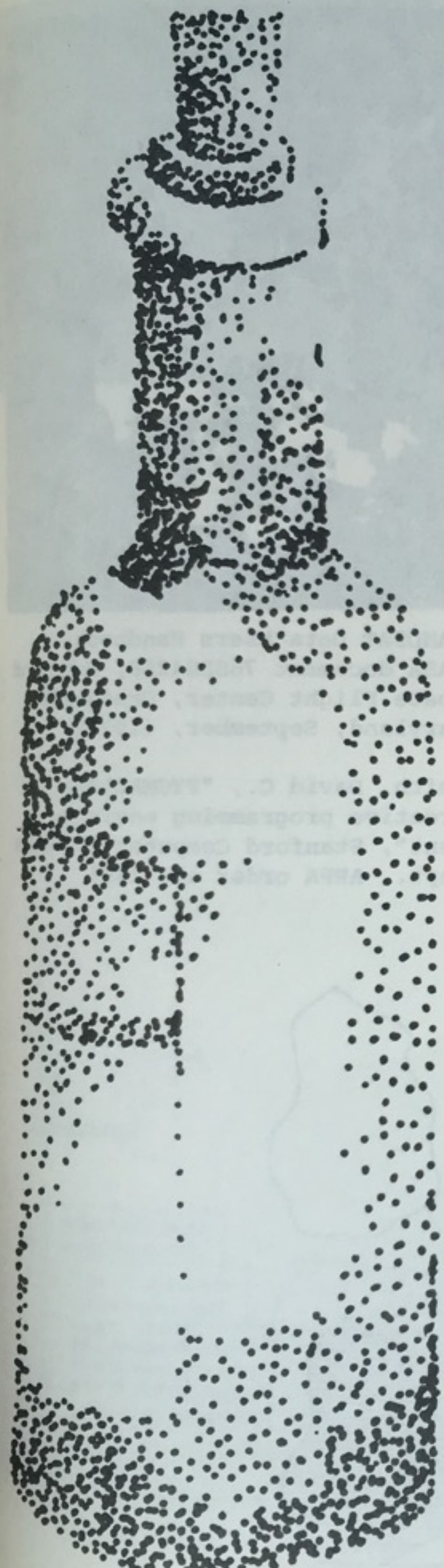
3. How does a large display interact with more than one user?
   Not knowing where they are looking?
   Knowing?

4. How does graphical interaction become affected by sound?
   In three space, shared by more than one user?
   In 2 1/2 space, with ear phones, with each user hearing sound relevant to him, his task, and physical position?

5. Stepping back (literally), how does baton-like stylus achieve the input counterpart to zooming in order to easily address large versus detailed graphics?

6. Presuming no additional factors of strain on behalf of flicker, scintillations, rear projection, is there a strain factor introduced by size and the prerequisite for additional body movement to pursue the place?

7. How does size, and consequent body engagement, effect the user's memory of the image?



5.3.2 Shape-Oriented Computer Graphics

This subsection concerns textures and, when they exist, the boundaries that delimit them. The Abstract of this proposal refers to a recalcitrance due in part to the line-based origins of computer graphics. The strokes of an electron beam go back to the specification of ENIAC. Additionally, much of the world of static graphics is a world of vectors: the plotter, the storage tube, the computer output microfilm machine.

A straight line is defined by two points; it can have width, color, and the rhythm of dots, dot-dashes, dot-dash-dots, and the like. But lines do not exist except as the intersection of planes or as limiting contours. Nonetheless, we see 2-D and 3-D computer graphics systems, almost all of which use the line as the primitive element. It defines planes which, in turn, define solids.

Here we submit that the primitive element is the dot, not the line. Designing a graphics language that allows for the control of dots, by defining, transforming, and associating collections of them is our current concern. We will call these collections "blobs." The term is used in lieu of "shape" only to impart the concept of soft edges that can intermix spatially the same way colors mix chromatically.

A blob is composed of boundaries (not necessarily visible) and containments. It can transform itself visually without any descriptive change, analogous to printing the same photograph on ranges of high- to low-contrast paper. Also, it can move, migrate and meander.

1. Boundaries are physical, logical, ephemeral, or implicit. An example of physical can be as simple as a circle or as complicated as an ink blot. A logical boundary is equally "crisp" or hard-edged, but manifests itself as a bounding

or delimiting force, rather than as a graphical element. An ephemeral boundary is a zone of mixing akin to the orange of a sunset steeling the blue of the sky. An implicit boundary is a visual inference, with or without graphical justification.

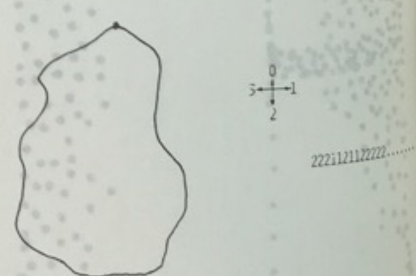
2. Containments have: color, scenic content (i.e.: a photograph), or texture. Color can be continuous or undulating combinations of hue, saturation, and intensity. Scenes can be still-photographs or, with some enterprise, live video. Textures, the a-referential superset of the above, can range from the patterns of LOGO-like programs to the soft pencil work of life-drawing renditions.

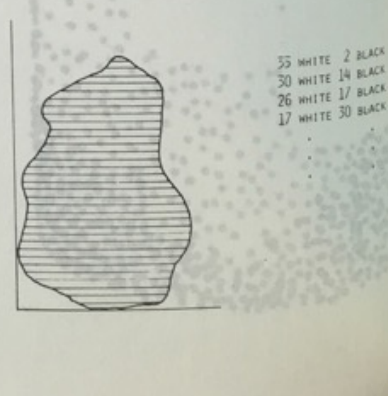
3. Transformations of these blobs can include pixilations, contrastings, mappings, interpolations, or random variations. Pixilation is approximated by what we currently call colorizing: the assignment of RGB, for example, to a gray tone of n-bits. Contrasting is illustrated by viewing various high-order bits of an image, similar to the adjacent Mandrill. Mappings can be discrete, per pixel, or paths from A through B, where A can be a value of chrominance or luminance, and B can be algorithm for change. Similarly, interpolations are mappings where B is the target value. And finally, random transformations are mentioned because our current work has revealed evidence of pattern recognition facilities gained by overlaying random transformations on the iconic fabric of a photograph, be it a face or Landsat image.

4. Motion is not mentioned above as a transformation. Boundary undulations, scale changes, and "tremors" are illustrative of motion without transformation. This is illustrated in the reverse sense in cell animation, where, for example, a decrease in size is used to give the illusion of receding. To migrate, however, implies movement about a 2-D

LANDSAT Data Users Handbook, NASA document 76SDS4258, Goddard Space Flight Center, Greenbelt, Maryland, September, (1976)

Smith, David C., "PYGMALION: a creative programming environment", Stanford Computer Science Dept., ARPA order no. 2494



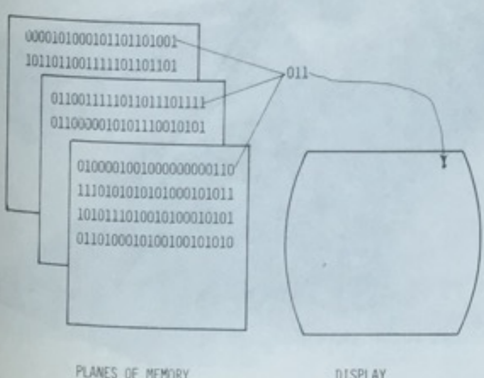


or within a 3-D world. On the other hand, the meandering is presented to conjure images of figures in murky water, coming into and out of the fog, or camouflaged by foliage.

These four characterizations differ enormously from the proverbial ΔX and ΔY worlds of calligraphic displays. This difference is not just a "fuzzification" of line drawings that happen to depict closed figures that happen to have color or some other infill. These are conceptually different postures toward graphics. They are reminiscent of the silver image, they would afford comfort to the video-artist, and they are what we see in nature.

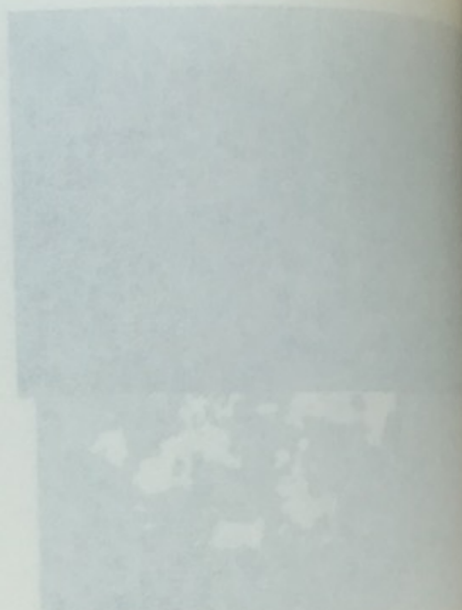
The scope of this task is to understand the differences, to implement a language that allows for the control of shape-oriented graphics, and to use it in applications where it can be exercised to amplify conversational fluency.

Difficulty arises because people usually draw with one hand, using a pen or pencil, emitting a line. Similarly, a point that moves over time describes a line. We talk of a line of sight, a family lineage, linear functions, and the thin line between imagination and madness. Lines are not rooted just in the sweep of electron beams.

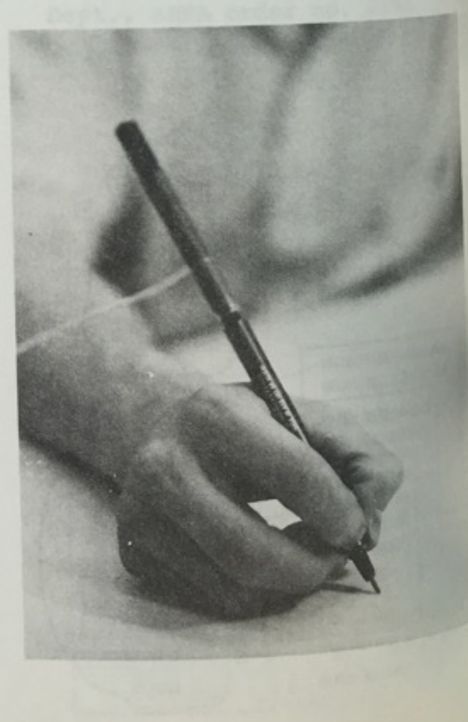


5.3.3 The Intelligent Pen

Work in sketch recognition and interactive systems has shown us that input media are sorely lacking in expressiveness. We have made the case that an interactive system requires multiple modes of communication, and that the ease with which one can communicate can play a critical role (section 1.4.4, Encouragement to Interact). Available graphic input devices fail in these respects: although all report X-Y coordinates with varying accuracy and ease, none do more. How a set of points is generated is often as important as what they are. (Was the user drawing with a puck or a light pen and how hard was he pressing?) The answers to these questions can provide valuable data to the interactive process.



We propose an intelligent pen that would encompass the notions of gesture (subsection 5.3.4) and feedback (subsection 5.3.9) and will expand the notion of stylus to something akin to an artist's brush. The pen is labeled "intelligent" to indicate that it would provide the necessary data for intelligent systems to operate; it does not indicate that the pen itself would have intelligence (would that it could). There are several areas in which we propose to make the pen more responsive to the user. They are described in the order in which they would be implemented.



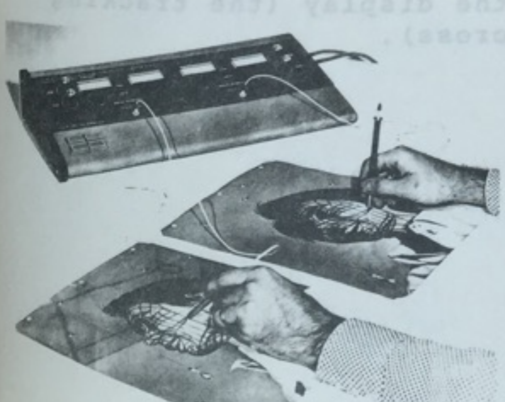
The first stage in the development might best be described as simple enhancements. These modifications do not alter the basic characteristics of the pen, but add dimensions that enable it to report more information than position. We have already built pens that sense the pressure and have an active eraser. These are valuable first steps. The ability to report orientation and rotation is the next step. In the context of sketch recognition systems this would aid the machine in its inference-making ability, and in the context of creative systems would allow the user to push, pull, and swing objects around the display without specifying any additional parameters. The pen would still have the feel of a ball-point or a pencil, but would have greater versatility.

Next we would change the tip so that it no longer simulates the medium of pencil and paper. The purpose is to include direct pen feedback. Note that the pressure pen is capable of providing feedback to the user in that the image generated can vary with the pressure applied. That feedback is indirect; it comes from the display, rather than from the pen itself. A pen with a soft tip can add to that feedback directly. The pen would be resilient, with the end made of rubber, perhaps, and would bend under pressure. It would be similar to a brush.

There are situations where neither the puck nor the hard-edge pen may prove to be the ideal input device. We are merely stating that no single pen can meet all the specifications of the ideal graphic input device. Thus the next stage would be to make all of these diverse styli available at the same tablet, and selectable in rapid order. This is not so much a hardware addition as a configuration change: Few tablets are amenable to having several pens available and active at once.

After making all of these pens available and attached to the tablet system, we would modify the tablet to allow all of them to be used at the same time, each reporting its position separately. This would allow a user to communicate with two hands or several users with n-hands at once. It would also enable the user to leave various pucks scattered around the tablet as pointers and indicators. To make this more useful, we would implement sensors in the pen that detect whether that pen is being held or is resting on the active surface. Graphic entities would be able to be defined by many parameters at once: A circle can be described by pointing at its center

Sutherland, Ivan E., Robert F. Sproull, and Robert A. Schumacker, "A characterization of ten hidden-surface algorithms" Evans and Sutherland Computer Corporation, Salt Lake City Utah, (1974)



with one hand, and indicating the radius with the other; lines would be able to be moved by manipulating both ends at once.

Feedback would also be incorporated into the various pens. Direct force feedback has already been discussed in reference to the soft tip, but visual feedback would also be added. The pen would become an independent output device. Its color, perhaps its temperature, would be parameters. This would provide an output path from the machine that is peripheral to the display, and that can vary in resolution from simple colored lights inserted into the pen's transparent end to having the world's smallest television built into the pen.

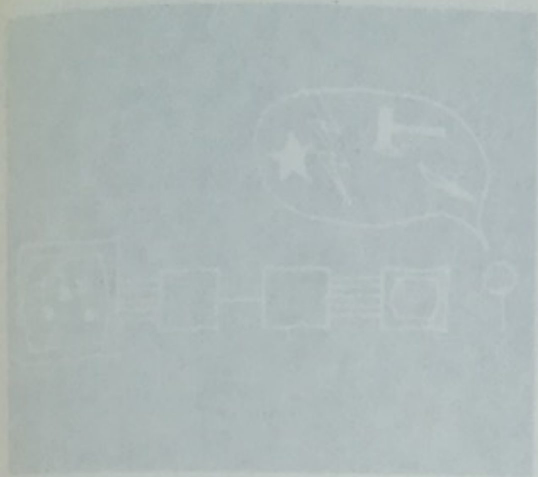
The last stage of development provides involuntary and supplementary inputs. We would create sensors in the pens that report where on the barrel the user is holding it, as well as incorporating galvanic skin response sensors.

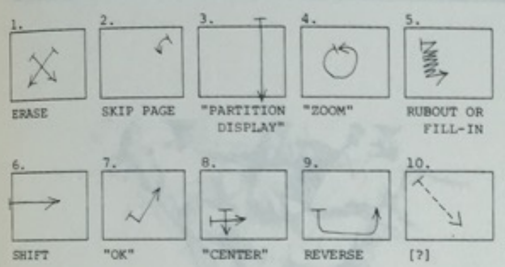
Pen/Pencil Stylus: Hard-edged, pencil like, used as a normal pen. This is the only input device that can be used for drawing as it requires the same hand movements that one would normally associate with a normal pen or pencil.

Movable Puck: Most accurate graphical input device; has parallax free cross-hairs. They are unwieldly drawing devices, and are held in a completely different manner from normal pens.

Fixed Joysticks: Removed from the drawing, these devices are most useful for pointing and indicating. They are amenable to modifications implementing force feedback.

Light Pens: Held similarly to a pen, but often require two hands merely to create the range of expression normally associated with a pencil. The use of a light pen can also create artifacts in the display (the tracking cross).





5.3.4 Gestures

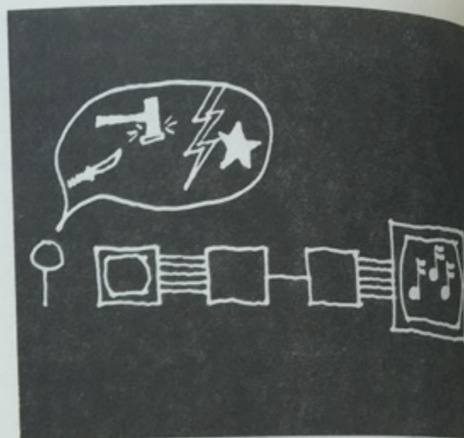
Most uses of the term "gesture" refer only to embellishments or adjuncts of a conversation. Gestures are visual in nature and we will explore them as a subset of graphical communication, but not under this usual limiting sense of the word. Gestures are essential to communication and expression. We do not, however, study gestures as cultural or semiotic elements; rather we concentrate on the following five types.

1. Gestures for specifications and manipulations: One example is a completely uninstrumented graphical editor. Simple extensions of our work with touch-sensitive displays (Appendix IX) will include taxonomies of commands: flicks of the finger to indicate translation, two-finger motions for rotations, expanding multiple-fingers for zooms. Particular attention will be paid to relating the gestures to physical realities. For instance, how does one move objects with fingers, and what are the most natural analogues in a touch sensitive display implementation?

2. Personalized gesture recognition: Hand gestures used in conversation are extremely personal and idiosyncratic. To force users into learning a standard set, like Palmer method handwriting, would miss the point. Gesture recognition on a user-to-user basis is a specific implementation of personalized systems (section 4.1). Evaluations such as speed and ease of use will be weighed against system overhead, complexity of the software interface, and training requirements.

3. Gestures as macros: Single sweeps of the hand can imply a series of actions in the same way that commands to a system can have further actions associated with them. User-definable sequences with conditionals will be implemented in the gesture-driven system.

4. Machine-mediated gestural conversations: Any communication involving syntax and personal symbology requires special handling in machine-mediated situations. For example, natural language, when used in discourse over a network, can be disambiguated somewhat by context. A limit is often reached, however, at which point the users need to learn more about each other. When already involved gesturally in one's own system, the user has an advantage in such dialogues: though using a natural and personal set of commands (gestures), the machine can decode and transmit the meaning to the other user's machine where it is translated into that user's personal expressions. Care must be taken so that misunderstandings are not amplified by the system.



5. 3-D gestures: Baton input devices will be constructed to move gestures directly into a fully spatial, time-sequenced modality. The batons will consist of three-axes accelerometers, distinguished by their small size and weight. This specification will be achieved through state-of-the-art components, specifically pressure-sensitive transistors. Only a low level of accuracy is needed in the twice electronically integrated acceleration data to achieve position. The subtle acceleration and velocity data contain most of the distinguishing features of intent, as seen in our work in sketch recognition (Appendix VIII). This new hardware expands the complexity and inference-making capabilities of our systems, exploding into the physical space of three dimensions --- the space in which we all continuously move. We will evaluate what we expect will be a pleasure, to interact with machines in our most natural and flexible mode, while maintaining personal style.

An exciting example of application for 3-D baton input is animation. One can imagine the experience of standing before a large wall-size projection TV, and

hurling (though without the step of actually letting go) a baton into the virtual space of the screen. The system decodes force, rotation, and direction information. A predefined object appears, moving with complete Newtonian grace, as specified by the motion of the baton. The object lands seemingly hundreds of feet away, as, perhaps, a cloud of dust slowly rises.

5.3.5 Cursors

The cursor and its poor cousin, the tracking cross, have long been at the focus of the man-machine interface. Cursors serve five essential purposes:

1. They coordinate input and output position, as with a track-ball or tablet.

2. They allow a light pen to draw on a black screen.

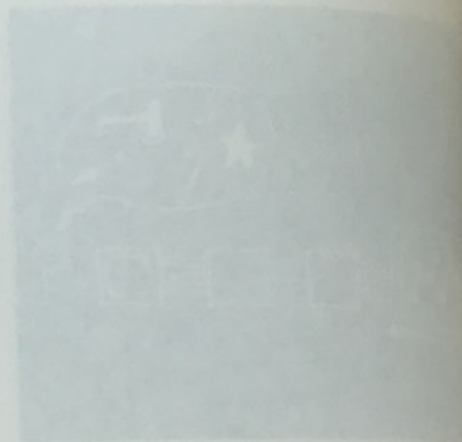
3. They identify to the user areas, objects, characters, and positions that the computer "knows about."

4. They give feedback without changing the picture, as before the pen touches the tablet.

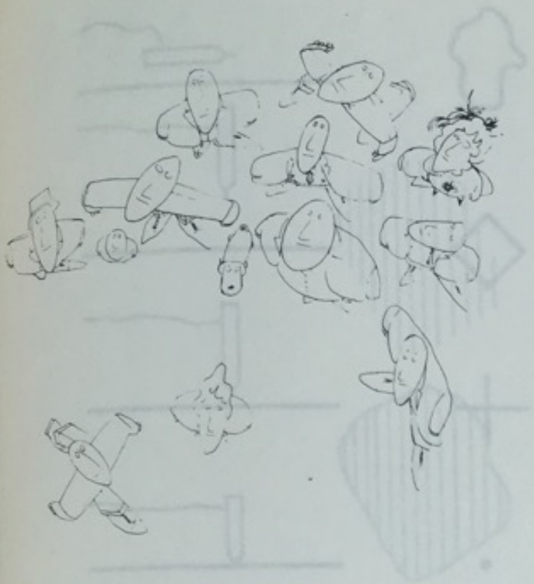
5. They provide a vernier effect, enabling accurate positioning of input.

Even though some of these features can be obviated by better hardware, such as an input device perfectly registered with the display (see subsection 5.3.11, Seeing Through Your Hand), the feedback process of the cursor is worthy of exploration in its own right.

We generalize the notion of the cursor in this context to include all graphical feedback that does not result in an image change. This categorization is not always clear-cut and may depend on how literally the cursor expresses its intended purpose. Very often, the cursor is used to indicate the result of a (permitted) user action, e.g., where text will be inserted/deleted or where a subpicture will be displayed. Sometimes more information will be conveyed, as in the drawing program at Xerox-PARC in which two angle brackets delimit the size of the area to be used as the "brush."



Shoup, R., untitled video tape shown at ACM/SIGGRAPH Conference, Philadelphia, July, (1976)



If such a brush were displayed as it layed down the "paint," it could be considered part of the image and still remain a cursor.

Even less distinct is a subfigure being dragged by an input device. The subfigure is a cursor as long as it is moved, but it becomes part of the picture whenever (for instance) the user presses the pen to the tablet to insert the subfigure into the picture. The subfigure need not ever be inserted into the picture, but could be used solely as an aid to visualization and evaluation, as is done in the YONA system (Appendix X, Architecture-by-Yourself) when a scale person is made to "walk" through a plan.

Cursors can have many attributes:

- Color
- Shape
- Movement
- Alternation (e.g., blinking)
- Picture

and in an expanded concept of graphics:

- Sound
- Feel

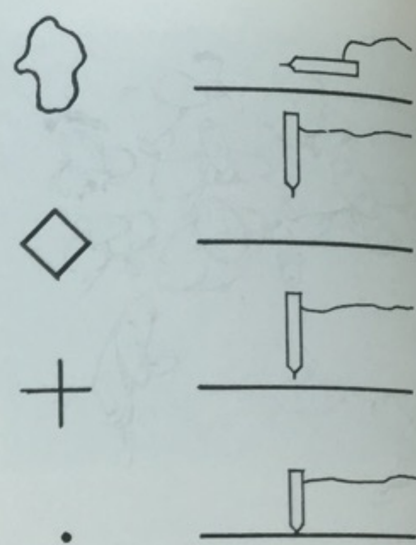
Kriloff, H., "Human factors considerations for interactive display systems", ACM/SIGGRAPH Workshop on User-Oriented Design of Interactive Graphics Systems, Pittsburgh, October, (1976)

Vartabedian, A., "Human factors evaluation of several cursor forms for use on alphanumeric CRT displays", IEEE Transactions on Man-Machine Systems, MMS-11, (1970)

As an element of the computer-created graphical medium, cursors can render the medium transparent. There is sufficient precedent in human factors research on the optimal nature of cursors such that this knowledge should find wider application. Our concern is to make use of the wider channels of feedback to which cursors lend themselves. The following projects are offered as the beginnings of our effort to exploit those channels:

<u>Soft Cursors</u>: The distance of the pen above the tablet can be expressed through variations in cursor shape and size. The form at each height can be chosen so that it is most useful at that particular level, perhaps providing a large amorphous blob when the pen is too far from the

tablet for accurate read out. As the pen is brought closer to the active surface, the shape becomes more definite, narrowing to a point when the pen is touching.



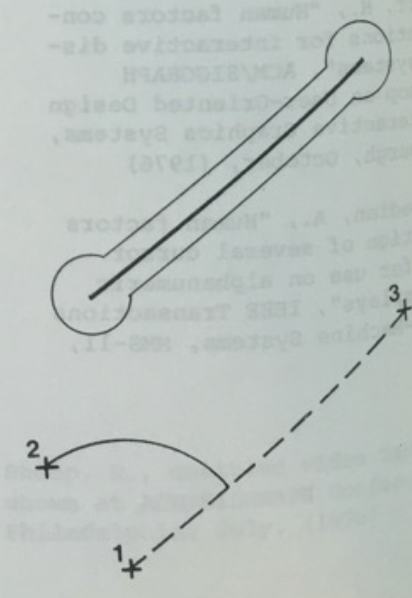
External Effects: The cursor need not be constrained to follow the position of the input device in a linear fashion. Sutherland's SKETCHPAD aided the user in latching lines together by providing bone-shaped gravity fields around them. If the cursor was allowed to get within the field, it attached itself to the line.

Another effect, used in drawing arcs, changed the coupling between the cursor and the created figure by using the pen position to specify the length of the arc separately from the radius. A similar effect is used in drawing lines of a specific angle, in which case the cursor position determines the length of the line.

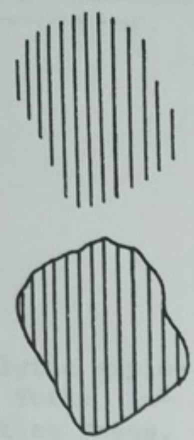
Sutherland, Ivan, "SKETCHPAD: a man-machine graphical communication system", Ph.D. thesis, MIT, (1963)

Knowlton proposes an effect by which the resolution of the input medium may be altered to provide fine input positioning with a coarse input device, in this case a 12-button touch-tone telephone. We propose a similar technique for use with a tablet in which the coupling between the two is nonlinear, as a function of speed or intent. These three examples are evocative of ways in which the feedback mechanism of cursors may be explored.

Knowlton, K., "Computer displays optically superimposed on input devices", to appear in the Bell System Technical Journal



Labels: Cursors can serve to identify objects and positions, as on a map having numbered dots keyed to a list of landmarks or buildings. The identification symbol need not be limited to the dot or the cross hair, but can make use of a range of effects that make a particular item on the display stand out, as described in subsection 3.1.3, Focusing. In a dynamic system, a label may be set up to move in synchrony with some aspect of the model, such that it represents a process rather than just a position. If several such cursors are connected to different systems, they can serve as a means of perceiving the relationships between those systems.

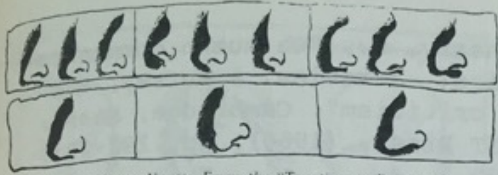


Manipulating and Creating the Image: The PAINT program (subsection 5.1.2, Complex Descriptions and Displays) uses a "boundary plane" as a tool in making a picture. This scratch plane is used to generate parts of the display that will not appear in the finished product, such as grid points and boundary lines. We intend to generalize and expand this concept to include all communication with the machine about the drawing.

Drawing with your Eyes: As mentioned in subsection 5.3.10, eye tracking places special requirements on the cursor, for the user must be able to acquire all necessary information without averting his gaze, lest he inadvertently change the picture. This requirement presents the utmost challenge to cursor capabilities, drawing on a multiplicity of modes, including sound.

Computer-mediated Interpersonal Conversations: The cursor can be used to communicate nongraphic information relevant to the transaction in progress. Given two cursors, each visible to both parties, but each one under the sole control of its owner, the form of a particular cursor could be a function of the distance of the corresponding pen from its tablet as described above. The cursors in this case contribute to a sense of presence, giving each party of the conversation some information even when no one is drawing. The clues need not be limited to a simple symbol at the pen position, but can be expanded to encompass light and sound in the participants' environments.

Mediation of Control: A variation on the above model is to provide just one cursor for the two participants, furnishing a means for arbitrating the locus of control. Several methods for mediating control can be investigated. Control can be made available whenever the active pen is lifted from the tablet, or at constant intervals of time, or it could be "stolen" through sufficiently violent (or gentle) motion of the pen.



Leonardo da Vinci: *From the "Treatise on Painting"*

5.3.6 Caricature

The dictionary defines "caricature" as an exaggeration of a gross and often ludicrous sort. Mime, music, and sculpture use caricature; thus, it need not be graphical, i.e., in the form of a *cartoon*, although that is the form by which most of us have come to know the art. The word "caricature" itself derives from the surname of two Italian cartoonists of the late sixteenth and early seventeenth centuries, the Carracci cousins: Lodovico (1555-1619), and Annibale (1560-1609). They were apparently the originators and inventors of true portrait caricature, and their work made a considerable impression upon contemporary connoisseurs and critics in Rome and Bologna.

Kris, E., "Psychoanalytic explorations in art", New York: International Universities Press, Inc., (1952), Chapters 6,7

Graphical caricature -- drawing, painting, etching, cartoons -- has been the vehicle of a wide variety of gifted artists. The caricatures, of Daumier and da Vinci, for example are classic, and are primarily caricatures of *types*: the "angry man," the "old man" of da Vinci; the vain, the self-important, the ingenuous sorts of Daumier. The work of the English critic and caricaturist, Max Beerbohm, was, in contrast, primarily of *individuals*, of Disraeli, of Oscar Wilde, of Kipling.

Gombich, E.H., "Art and illusion: a study of the psychology of pictorial representation", New York: Pantheon Books, (1960), Chapter X

The skill of the caricaturist lies in his ability to facilitate *recognition* by a wide public of some personage, or of some type. The artist must have the facility to abstract the most important and *information-bearing* features from the subject. When *recognition* is essential, as, for example, in police renderings of crime suspects, a drawing *tending toward* caricature may be of more utility than camera photographs of the suspect, in that a caricature is a rendering predicated upon recognizability, a systematic selection and distortion to ensure recognition.

Lorenzo Bernini. *(Cardinal Scipione Borghese)*

The principles underlying the selection of invariants, which lie at the heart of the caricaturist's skill, may well be applicable to the design of a system that must occasionally present graphic material to the user under conditions where maximum recognizability is necessary. Imagine that the user wants to review quickly a series of previously drawn sketches in order to select one of interest. Imagine further that the routines enabling the presentation are additionally able to select, compress, exaggerate, and overemphasize various features of the sketches, such that what is re-presented are not the original sketches but *caricatures* thereof. Optimally, the selection and compression that is effected is such that the principles underlying the act of caricature are invoked.

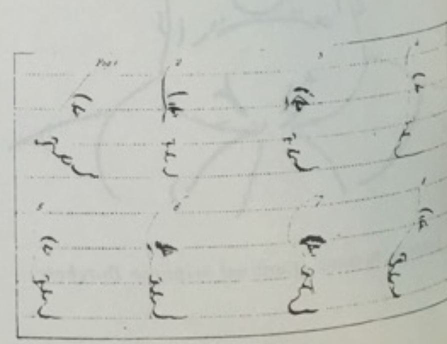
How may such principles be isolated? One approach would be the on-line study of subject artists drawing *caricatures* first of simple objects, and then of increasingly more complex scenes (Cf. Appendix VIII, "Graphical Input through Machine Recognition of Sketches"). This would be no easy task, but on-line study of caricaturing styles might provide some beginning insight into what is done to the components of simple shapes and figures to render them as *caricatures*. Abstracted principles might then be embodied in the machine as programs shaped by the principles of caricature. We already have sets of routines that "characterize" simple lines and shapes and go on to rectify and normalize them if certain criteria are met (Cf. Appendix VIII). In contrast, routines that expand, amplify, and exaggerate, embodying criteria apropos of caricature, might be developed. These caricatured lines and shapes could then be re-presented to the sketcher for graphic commentary and correction, for the sketcher to amend with stylus, if he so desired. The cycle would be part of a procedure to impart to the machine a set of protocols for caricature.

A paradigm for further work in this direction is provided by attempts to

Cherry, C., "On human communication: a review, a survey, and a criticism", Cambridge, Mass.: MIT Press, (1966), pp. 292-293, 299

Phillipon. (*Louis Philippe*)

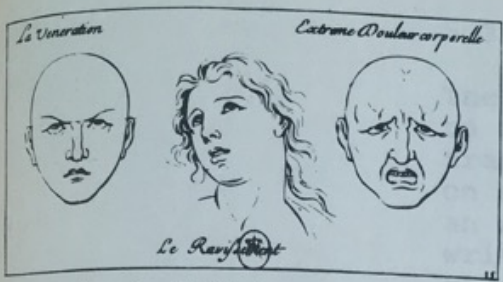
Gibson, J.J., "The senses considered as perceptual systems", Boston, Mass.: Houghton Mifflin, 1966



understand the perception of *events*. Gibson (1966) has argued that the perception of any event involves two components: (1) detection of invariant information specifying the nature of the change (transformational invariant), and (2) the detection of invariant information specifying the structure that undergoes change (structural invariant). Events such as: the *ball* rolls, the *flower* grows, etc., illustrate this principle. The perception of *faces* over time has been so studied, aging faces being regarded as viscal-elastic events. Pittenger and Shaw (1975) have modeled the development of the adult face from that of the child by the application of a method of spatial coordinate transformations to characterize the remodeling of faces by growth. In their model, "...shear and strain transformations were compared as alternate formulations of growth produced changes in the shape of human profiles." *Shear* reflects the degree to which the main angle of the profile is oblique with respect to the perpendicular; *strain* is the force imposed upon bony tissue by stresses caused by the growth of soft integuments, providing the primary shape of the head.

We would not liken growth-induced changes in appearance to *caricature* necessarily, although the proverbial late-childhood "growth spurts" and the preteen "awkward age" might suggest this, especially to those individuals going through these stages. The commonality lies in that certain aspects are changing according to some principle, while others remain constant.

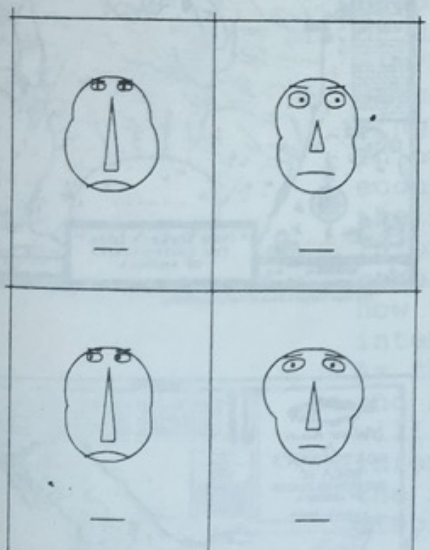
The portrayal of variance and invariance juxtaposed and intertwined is dramatically (and humorously) seen in variations upon a cartoon face produced by Chernoff (1973). The features of this face correspond to the k-components of a data point. The variations in shape and expression reflect different loci in a k-dimensional multivariate statistical information space. The face is effectively a data display.



Le Brun: From "Le Méthode pour apprendre à dessiner les passions." 1696

Pittenger, J.B. and R.E. Shaw, "Aging faces as viscal-elastic events: implications for a theory of nonrigid shape perception", Journal of Experimental Psychology: Human Perception and Performance, 1 (1976), pp. 374-382

Jacob, R.J.K., H.E. Egeth, and W. Beran, "The face as a data display", Human Factors, 18, (1976), pp. 189-200



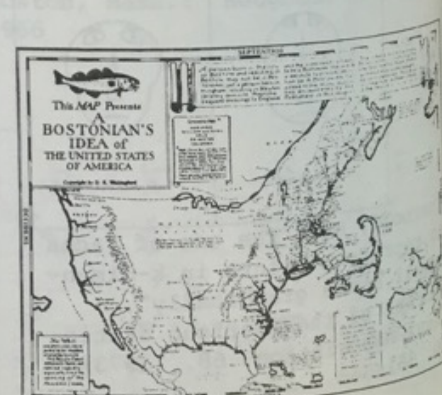
Chernoff, H., "The use of faces to represent points in k-dimensional space graphically", Journal of the American Statistical Association, 68, (1973) pp. 361-368

We feel that selective distortion and exaggeration of a shape such as that used in caricature but now used for the sake of recognition and selection, may form an effective basis for orchestrating some aspects of graphical conversations. Highlighting, prompting, hinting, suggesting, even *insinuating* -- these are some of the modulations of discourse that might be enabled. A three-pronged attack on the development of these themes might be formed by the intersection of:

1. Already ongoing and well-developed techniqeus for "on the fly" sketch recognition
2. Studying subjects doing on-line caricature sketching to extract underlying principles of caricaturizing transforms
3. Extending the leads furnished and implied by the work of investigators such as Jacob, et al., toward the end of caricaturizing (*presenting* with modulated emphases) *abstractions* now, such as collections of data, rather than faces, but employing recognizable presentation forms such as faces, maps, etc.

In this last connection, the reader is reminded of map sketches of the United States made by, for example, a Bostonian who might draw an enormous Massachusetts Bay and Cape Cod with the balance of the country as some sort of *Terra Incognita*. Similarly, a Texan's view might show a gigantic Texas, with the balance of the country being vestigial. Maps of the world's reserves of oil, now increasingly more common in newspapers and magazines with the current "oil crisis", are another example of informative distortion. Each region is scaled proportionally to its reserves. Just as with caricature, it might be bad geography, but it is a good way to highlight information.

The New Yorker's View of the United States



The Bostonian's View of the United States

5.3.7 Color Adjuncts

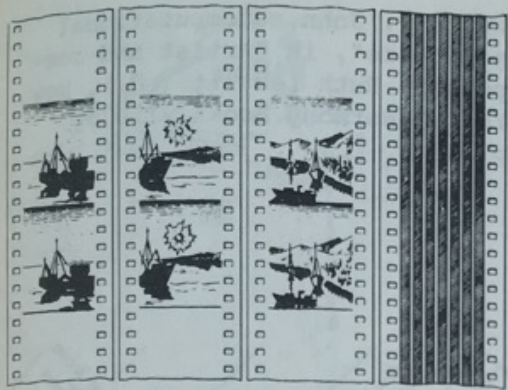
The variety of ways in which color could be used in visual communications has traditionally been quite limited. Used on a local basis, color has served as an emphasizer (red versus black typewriter ribbon) or as a delineator to resolve spatial ambiguities (multiple line graphs drawn with colored chalk). In addition, color has been used to a limited extent as a secondary information-encoding element in, for example, multicolored forms and primitive-land-type mapping codes. In many recent attempts to use color in a complex display, tests have shown that beyond a simple spatial configuration color can add confusion.

We feel that can be attributed to the lack of sophistication in color perception by the user of a visual communications system. For example, one of the most powerful aspects of color is its extension-free three-dimensional properties of hue, saturation, and brightness (see section 2.5). Yet most people have not been educated to analyze or develop a fast reflex to a color, as dim/bright, hue name, or degree of saturation, but think, rather, of a single name (pink, chartreuse, red). In our society, people have been accustomed to appreciating colors for their aesthetic beauty and not for the information that they convey. Even researchers in map coding will remark how "pretty" a map looks, forgetting the intended functions of the color codes. As the user becomes more sophisticated and accustomed to the use of color, he will be able to more easily decode the information and be less distracted by the inherent attractiveness of the display.

We have planned a number of projects that will determine the limitations of color in the man/display interface and that will enable us to evolve a program of user education in the perception and generation of intelligent color in graphics.

1. Perception of the Three Dimensionality of Color:
By using the dimensions of hue, saturation, and brightness to delineate, associate, or code graphical data, one can add three extension-free variables to a visual display. We are interested in measuring the ease by which an observer can perceive constancy in one color parameter as the other two are varied. Thus the background or actual figure colors can be used to convey three distinct pieces of information. Due to the natural association phenomena mentioned in section 2.5, the gamut of usable colors in a display may have to be restricted, depending on the particular spatial context or parameter associations.

2. Color in Coding Two-Dimensional Space:
One primary area of color education is to teach and reinforce the concept of chromaticity space as a two-dimensional area with saturated colors along the perimeter, which become desaturated as they approach the white point in the center of the figure. Because the rainbow motif has been extensively used in advertisements, logos, and graphic arts media, human beings have become accustomed to the linear ordering of hues. In fact, in simple color coding systems, the use of this natural ordering is exploited without exception as an analogue to a monotonic scale. The use of a two-dimensional color plane enables the user to convey spatial or two-dimensional variable information as an extension-free variable.



Four films, three picture and one sound, designed for the presentation of a Cinerama film.

5.3.8 Sound-Sync Graphics

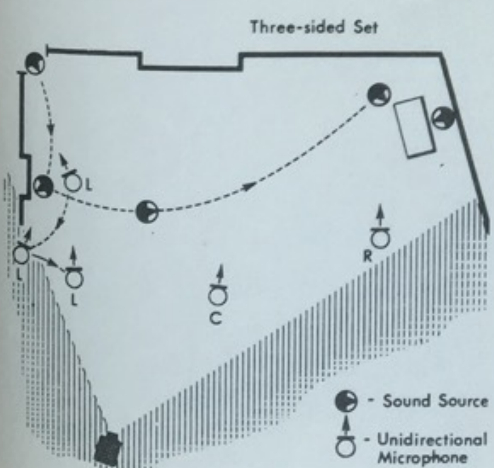
As our understanding of interaction and the importance of expression in a variety of modalities increases, sound takes on new meanings for the machine environment. Sound-sync (the film production phrase used to indicate the relationship of sound to picture) is an application of the philosophy of this proposal in the area of sound.

Commercial products are only just catching up to "audio and visual" mixed media presentations (other than, of course, television). An Eastman Kodak advertisement suggests we "bring the talkies home," with the sync-sound capability of home Super-8 equipment. The increased use of sound in home videogames is another example. This obvious movement among manufacturers toward more sound and better buttons (for example) is simply a small move in the sound-sync direction. We predict that those games that are the most interactive will be the most popular.

We will explore the relation of sound to graphics in the following areas.

1. <u>Simulation Enhancement by Sound</u>: We have all experienced fireworks, the combination of dazzling graphics on a mammoth scale with sound to match. Those who have seen fireworks from a distance, or worse, on television, realize the lack of impact fireworks have if the scale of either the visual or aural experience is reduced. Activities scheduled to take place within our Media Room (subsection 8.3.4), though neither of the magnitude nor purity of form of fireworks, require careful integration of the visual and aural modes.

Animation environments will be enhanced through the addition of the modality of sound to interaction. Newtonian simulations couched in such an environment could respond with Doppler-shift effects, phase-change due to head

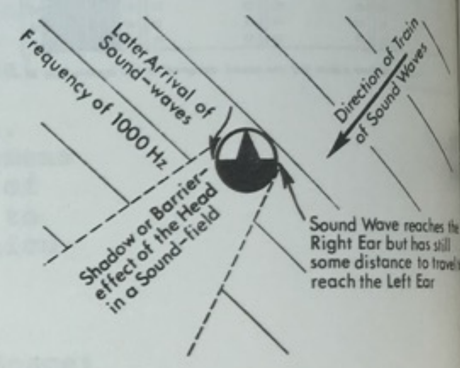


orientation and motion-to-sound relation. A simple synthesizer, under program control, will be available to the simulator for the study and implementation of such enhancements, including personalized system configurations of the acoustic environmental response.

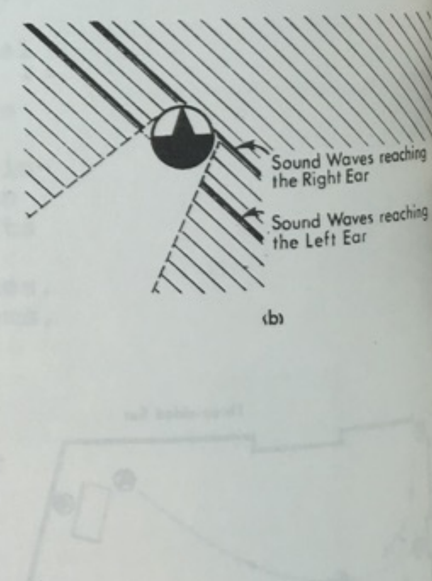
2. <u>Process Representation in the Aural Mode</u>:
Our ongoing animation work, (subsection 8.2.1) asserts that the utilization of the computer for a *new* and valid "filmic" medium for art requires a reexamination of the powers and presentations that an animation system must provide. Explorations of the process-product relation postulated in the animation work apply equally to the aural mode. The possibility for the conceptual embodiment of idea in sound is as valid as in image. However, careful examination of the nature of the receptive systems (hearing and vision) is necessary. Experiments in relating aural harmony with graphic phenomena do not consider the perceptual differences between the senses, and attempt to analogize without correlating the relation of the art form to its perception.

The ability of the ear to distinguish and hold in memory complex horizontal (time) as well as vertical (harmonic) relations will be exploited to try to communicate graphically, conceptual ideas such as resonance, decision, fate, and the dialectic of Hegel.

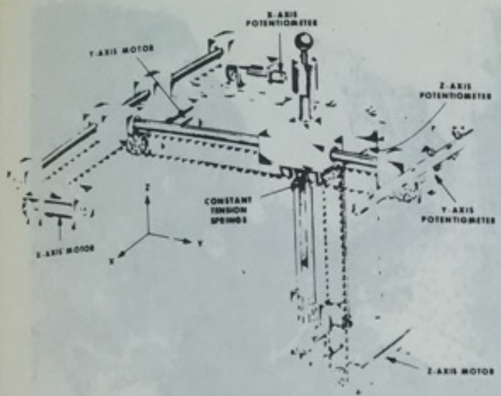
Whitney, John, "Computational periodics", in "Artist and computer", Ruth Leavitt (ed.), New York: Harmony Books, (1976), p. 80



(a)



(b)



Three dimensional force feedback device by A. Michael Noll

Batter, J. and F. Brooks, Jr., Information Processing, 71, (1972), p. 759

Noll, A.M., "Man-machine tactile communication", Ph.D. thesis, Polytechnic Institute of Brooklyn, (1971); J. Soc. Inform. Dis., 1, (2), (1972)

5.3.9 Input Feedback Systems

Feedback has been defined as the representation to the user of parallel processes occurring in the conversation. One of the means by which we may obtain this feedback is via the input medium itself. The input device is thus used interactively for output. There are several reasons why this is a good approach. First, the user's attention is already focused on the input device, and therefore the feedback can be direct and immediate. There is no diversion or re-direction of the user's attention in order for him to receive and interpret the information. Second, there are many modalities available to the input device that are not available to other devices presenting a display. The user is in physical contact with it, and the feedback is thus physical as well as visual and aural. Third, no distortion of the display or environment is necessary.

There are several examples of devices that have made use of physical, force feedback. Batter and Brooks built a two-dimensional force feedback puck. This device was used to explore the effects of physical force fields kinesthetically. A three-dimensional system consisting of the input arm from a remote manipulator, and the appropriate servo systems to allow full directional force feedback was also built. Normally, in a remote manipulator system, there is a close mechanical coupling between the input and output arms. In this system, there are no output arms. There is instead, a representation on a display. The computer controlled servo systems in the arm create the impression that the objects on the display have real mass and texture.

Noll also built a three-dimensional touch feedback system in 1971. This system also provided mechanical feedback through three stages that terminated in a knob available to the user. More recently, Wilson built a system where the input feedback is accomplished in three dimensions by strings. He is working on a new version in which positional and torque feedback will be provided.

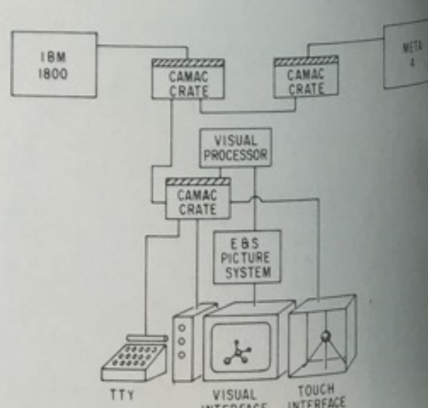
In our lab, we have built a Force Feedback Interact (see Appendix IX). This consists of a joystick mounted on the arm of a plotter-digitizer. Whereas the standard Interact maintains a direct correspondance between the motion of the arm and the force of the joystick, that loop has been interrupted by placing the motion solely under the control of the computer. The response characteristics can be varied by making it appear difficult to move the arm in some directions, and easy in others. The key characteristic of this type of feedback is that it is in the same modality as the actual input. The response to a force is either another force or a resistance.

This type of direct feedback can be extended to other types of input devices. We postulate a tablet where the surface is not constrained to be flat, but can be distorted into a three-dimensional curve. The orientation of the surface can influence the preferred direction of the pen. This implementation eliminates the clumsy aspects of plotter arms and manipulator arms, and substitutes a more natural input medium. Ultimately, means should be developed by which it will seem as if the pen is moving through an anisotropic, viscous medium.

We also postulate feedback systems that are not associated with force and physical motion. These have been discussed in relation to the intelligent pen and are primarily visual and textural.

Force feedback Interact

Wilson, K.R., "Multiprocessor molecular mechanics", in "Computer Networking and Chemistry", Peter Lykos (ed.), American Chemical Society Symposium Series, 19, (1975)



Touchy Feely, Kent Wilson

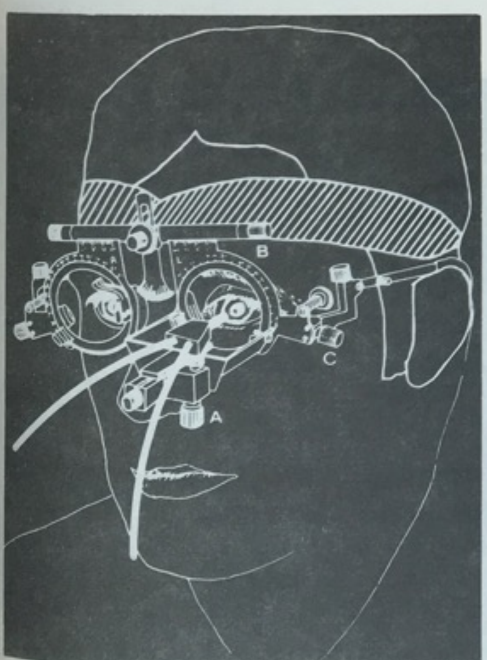
5.3.10 Drawing with Your Eyes

Given that this proposal centers upon graphical, and therefore visual, modes of conversation and communication, the potential of the eyes as an *output* device as well as an input device, namely as *input-feedback* systems, deserves exploration (Cf. subsection 5.4.9). Note in the Schedule (section 5.2) that this research comes in the fifth year and therefore represents the fullest extension of ideas and philosophy in the proposal.

Young and Sheena, "Eye-movement measurement techniques", J. of the APA, 30, no. 3, (1975)

Behavior Research Methods and Instrumentation, 7, no. 2, (1975)

Instruments for tracking eye movements are commercially available, and hence the technological capability is currently at hand. This capability has been applied to diverse areas: instrument panel layout, advertising, cognitive processing,aesthetics, and as aiming devices for both quadraphlegics and weapons systems. We will explore the ability of such instruments to specify spatially position, sequencing (lines), textures (oscillations), and motions as willful actions on the part of the user.

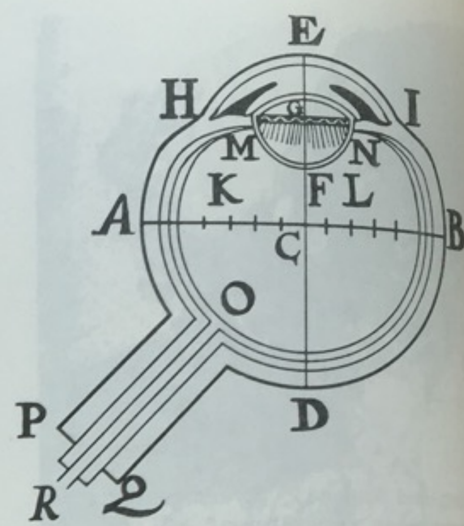


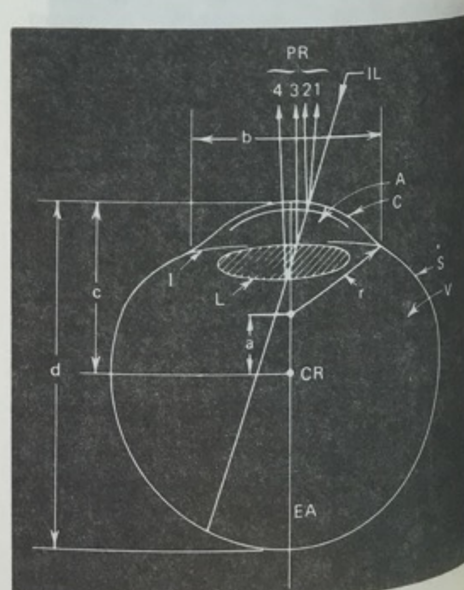
1. Drawing with your eyes:
Cursors (subsection 5.3.5) will provide necessary feedback, damp unwanted oscillations when engaged in certain drawing modes, and provide continuous "state-of-the-system" information. Experiments with texture-filling and abstract patterning will be conducted. Head-orientation independent of eye attention represents an added dimensional capability.

This input modality will be carefully evaluated and compared to existing (both now and then, five years hence) modes. Extension into eye gestures will be explored, postulating the eye-driven system as personalized and completely touch-free (manipulating data while folding the wash, so to speak).

2. Exploring involuntary motions as input:
One argument against the premise of this section is that eye movements are

involuntary and unconscious, and therefore inappropriate if not incapable of sufficiently controllable motions. A counterargument is that some involuntary motions of the eye may be tapped as a channel of information flow. Artists spend considerable time mastering "control" of their bodies, for example, hands in the case of painters. A broader interpretation might be that artists are trying to open an unobstructed channel from the internal to the external in order to "express" their art. How much of the control is pure and precise *specification* is debatable, particularly in the performing arts: acting, dancing, improvising. It is a simple extension into interactive personal systems to postulate this communication channel being tapped with a previously unachievable hardware/software system, not just for an artist (in the sense of highly trained user) but for each individual (untrained user). A careful examination of the distinctions between controllable/learnable eye movements, and involuntary/meaningful movements might yield a sense mode input of unknown and potentially extraordinary bandwidth.





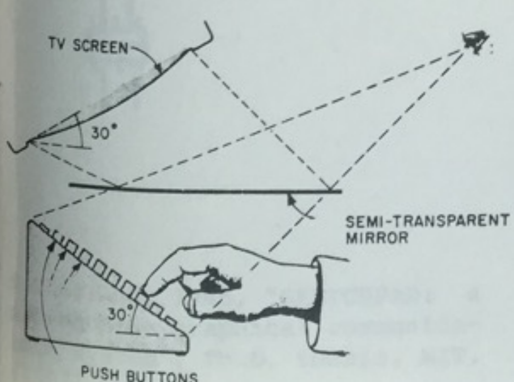
5.3.11 Seeing through Your Hand

Most computer input/output media lack the immediacy of pencil and paper. The system designer is forced to choose among an unsatisfactory set of compromises, none of which provide the full range of desired features. Light pens allow the user to draw on the output surface, but their unwieldiness and dependence on illuminated areas of the screen make them more suitable for pointing than drawing. Touch sensitive digitizers are a promising alternative, but lack the required accuracy and suffer from parallax. A separate tablet and display have proved successful in some applications, but depend on a tenuous hand-eye coordination that is easily lost if attention must be directed to the tablet itself, as when tracing a manually generated drawing. Transluscent, rear-projected tablets are another possibility, but are currently too expensive and cumbersome for general use.

Knowlton, Ken, "Computer displays optically superimposed on input devices", to appear in the Bell System Technical Journal

Knowlton, Ken, "Prototype of a flexible telephone operator's console", 12½ minute color 16mm film with sound

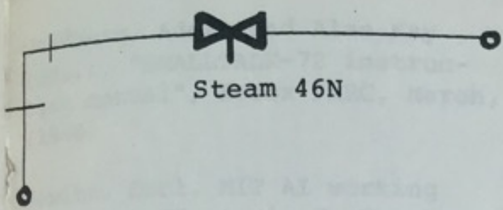
Knowlton has proposed a scheme for superimposing a display image over an input device by using a partially silvered mirror. Properly constructed, there is no parallax for either observers or the participant. Such a scheme was used to construct a prototype work station for telephone operators, superimposing labels and cues on a physical keyboard. The existence of tactile feedback from the display in the same space provides such an uncanny sense of close interaction with a computer that it must be seen to be appreciated.



The Knowlton scheme lends itself readily to graphics. We propose to explore that realm by substituting a tablet for the keyboard. This would offer the possibility of an intimately shared input/output space hitherto not achieved with a computer. Not only would such a scheme answer the objections raised in the first paragraph, it would offer the additional advantage that one could draw while seeing through one's hand. Since we know of no analogue to this feature in present-day graphics, an entirely new range of questions must be explored:

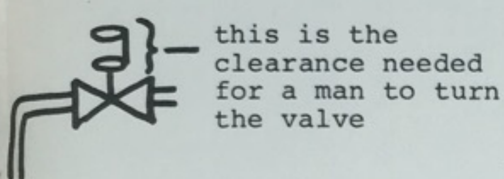
> Is seeing through your hand confusing? Knowlton asserts that it is *not confusing* when using the keyboard. This experiment will be the first trial using a tablet.
>
> Will it affect the differences between right- and left-handed individuals since left-handed people hold a pen differently than right-handed, obscuring the drawing in different ways?
>
> Will it affect the pointing and focusing power of the hand?
>
> Will drawing be easier if you don't have to move your hand to see behind it?
>
> Will it affect the use of short-term memory if you don't have to remember what is under your hand?

Our feeling is that the effects will be more pronounced when the technique is applied to dynamic images, and may therefore offer advantages beyond mere cost effectiveness.

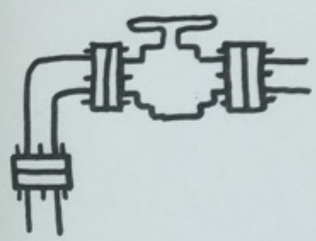


5.3.12 Knowledge-based Graphics

Most computer graphics systems force a separation between the manipulations of objects and the corresponding operations on their underlying meanings. The user of a computer-aided design system manipulates geometric elements while thinking of the objects represented. In those systems that combine the two, they are frequently inseparable. There are times when one would like to work in purely graphical terms, keeping the underlying semantics to oneself, while at other times the combination of the two would be extremely helpful. The projects outlined in this section are designed to give the user a powerful set of tools and, at least as importantly, a means of choosing and controlling them.



1. <u>Transformations from a Data Base</u>: As discussed in section 1.4.7, Tautological Transformations, the ability to work with multiple representations is one of the most useful capabilities provided by computer-aided design. Such a capability would allow a designer to work on a problem from several points of view, or for two designers to share a data base. For example, in the design of a chemical plant, a piping system could be displayed as a schematic diagram when designing the process, changing to a more pictorial representation when designing the layout of the plant, and finally assuming a highly realistic picture for purposes of presentation. If these representations are to be used by different members of a design team, the data base itself can become the shared element of the conversation.



2. <u>Calling on Previously Learned Skills</u>: A common feature in graphics systems, and something that we would like to make explicit, is the ability to call on skills and experience brought by the user to the computer terminal. The rubber-band line of SKETCHPAD is a good example. It calls upon experience derived from everyday life -- in this case from interaction with real-world entities

Sutherland, Ivan, "SKETCHPAD: a man-machine graphical communication system", Ph.D. thesis, MIT, (1963) which behave in a predictable manner. We have used this concept in our work with touch sensitive displays (TSD, Appendix IX) in a program to manipulate objects on a display. The user moves an object by placing his finger on the superimposed TSD. If the finger is placed near the center of the object, the machine translates the object as if coupled to the finger. Moving the object with its edge, however, causes it to rotate as well, as if it had mass and rested on a horizontal surface. We propose to generalize this scheme by allowing the specification of correspondences (analogies of entailment meshes) between elements of the displayed system and elements of some specified phsyical system so that the displayed system may be made to follow the rules of an arbitrary physical system. This association need not mirror the behavior of the displayed object in the real world. In fact it may be advantageous to cause it to obey a completely different set of rules. An architect may wish to move buildings on a site as if they were boats on a lake, yet moving walls as if they were made of clay. This analogy scheme would allow a wide range of such options.

3. <u>Model-Based Graphics</u>:
In the case where the behavior of the display of an object is modeled on its behavior in the real world, the computer medium can become transparent, allowing the user to interact with the system under investigation. The actions of the user may be augmented, giving him powers he would not possess in the actual setting. He may choose to remove dirt from an excavation by pushing an imaginary shovel, perhaps detecting bedrock by means of force feedback.

The user need not be restricted to affecting events in the modeled space. He could also change the causality of that space by modifying the program which simulates it. This capability implies the provision of a powerful and easy to use modeling facility, in the

Goldberg, Adele and Alan Kay (eds.), "SMALLTALK-72 instruction manual", Xerox PARC, March, (1976)

Hewitt, Carl, MIT AI working paper no. 92, revised, March, (1976)

Winograd, Terry, "KRL", Language Research Group, Xerox PARC, in press

manner of SMALLTALK or PLASMA. Such a feature would be used not only by the user to exteriorize descriptions of dynamic processes, but by the system programmer/subject matter expert in formulating the descriptions at each node in the entailment structure. The integration of simulation and knowledge representation is evocative of Winograd's work on KRL, which may serve as a model in this case.

4. Access to the Data Base:
The data base (entailment structure) must be more than just an implementation device. It must be a facility the user can make full use of to store insights (analogies) and find his way around the system. It will contain information not only about the problem space but about itself. Portions of the data base can be displayed in a variety of formats, by use of analogies to previously defined forms. A pointer based data structure could be viewed as a network, complete with boxes and arrows, as a sequence of LISP-like S-expressions, or as an illuminated manuscript. It would be possible to "jump through" a node to its underlying meaning, executing its simulation as well as examining the data explicitly.

The data base can also contain expert knowledge about the problem the user is trying to solve -- knowledge found through the exploration of analogies stored along with them. Another type of expert knowledge can be embodied in programs, which can be located through the same means. Note that we are not requiring that the machine *generate* analogies (although we intend to incorporate techniques as they become available) but are instead providing a framework in which they can be *inscribed*, as in the manner of subsection 1.4.10, Analogy as Ossified Agreement.

5. Machine Recognition:
When interacting with the knowledge representation, the user should not be restricted to playing the passive role of

observer. Neither should he be required to resort to typing at the keyboard to make his needs known. The use of gestures to communicate commands to the machine was described in subsection 5.3.4. More complex graphical input will require some level of intelligence in the machine, to recognize the nature of what the user is drawing. This capability will make use of our previous work in machine recognition and inference making to allow a facile means of entering information into the machine and in specifying what information should be retrieved.

	FAMILY					INTIMATES				VALENCES				AUTHORITIES			VALUES					
	Self	Mother	Father	Brother	Sister	Spouse	Ex-flame	Pal	Ex-pal	Rejecting Person	Pitied Person	Threatening Person	Attractive Person	Accepted Teacher	Rejected Teacher	Boss	Successful Person	Happy Person	Ethical Person	Σ	M-F	Ay
1							✓			✓		✓					⊗	⊗	○	5	3	0
2				✓	✓			✓						⊗	⊗	○	✓			6	(6)	2
3	✓		✓	✓	✓	✓			✓	⊗	○	✓	⊗	✓			✓			11	(5)	2
4		✓				⊗	⊗	○					✓							4	0	1
5	✓	⊗	⊗	○	✓	✓		✓						✓	✓	✓	✓	✓	✓	12	4	(5)
6				✓	○			✓						⊗	✓			⊗		5	(6)	2
7		⊗	✓	✓					○					⊗	✓	✓			✓	7	(5)	(5)
8		✓	○	✓										✓		⊗	⊗	✓	✓	7	4	(3)
9				⊗	✓			✓		○				✓	⊗	✓	✓			7	(6)	(3)
10					⊗		✓			⊗					○					3	3	0
11	✓	✓	✓		⊗	✓		✓			○	✓		✓	✓		✓	✓	⊗	12	4	(4)
12	✓	✓	✓	⊗			✓	✓	○	✓	✓	⊗	✓	✓	✓	✓	✓	✓	✓	16	4	(5)
13		✓		✓		○				✓	✓	⊗		✓		✓		⊗		8	4	(3)
14		○				⊗	⊗						✓							3	1	0
15		✓	○			⊗	⊗						✓							4	0	1
16	✓	✓	✓	✓	✓			⊗	○				⊗	✓	✓		✓	✓	✓	12	(5)	(4)
17	⊗			⊗	○	✓		✓		✓		✓	✓	✓	✓			✓	✓	11	4	2
18				✓	✓										✓	⊗	⊗	✓	○	6	(5)	2
19		⊗	⊗		✓						✓	○		✓	✓	✓	✓	✓	✓	10	4	(4)
20					✓		✓	⊗	⊗	✓	✓	✓	○							7	(5)	0
21							○	✓						⊗	⊗	✓	✓	✓	✓	7	(5)	(3)
22	⊗			✓		○	✓	⊗					✓		✓		✓		✓	8	4	1
Σ	7	10	7	12	10	7	8	11	2	7	4	7	8	14	13	9	13	12	10			
Id	22	13	18	13	12	16	11	16	15	13	13	16	17	13	13	-12	14	13	17		277	33%
M-F	-12	-15	12	15	15	-14	-15	14	15	-12	11	-12	-13	13	14	12	12	-13	-13		252	21%
Ay	13	18	17	12	12	-13	-16	13	-12	-13	14	11	-14	18	15	19	15	16	18		279	33%

Special Identifications, Case A.

5.3.13 Measuring Interaction

A major premise of this proposal is that interaction is at the crux of all man-machine communications. This section outlines a series of studies constituting a complete, system level understanding of interactive systems.

1. Modeling of Interactive Systems:
Such techniques as the repertory grids (subsection 2.1.2) developed by Bannister and Mair would be used. This would provide a measure of how people feel about using computers in various tasks, as well as a clear understanding of intricately related aspects of such systems, for example, feedback, bandwidths, degrees of personalization, and the physical machine.

2. Review of Existing Systems:
The metric obtained will be applied to systems that the Architecture Machine group and others have constructed for evaluation.

3. Analysis of Proposed Research with Regard to Each Project's Goal and Degree of Interaction:
This constitutes a preevaluation stage in which the model and simulation environment that it provides can eliminate the construction of devices and systems measured to be inefficent or unsuitable for interaction.

4. Publish Findings to Propel the Ideas and Values of Interactive Systems in All Applications Areas:
We cannot emphasize enough our frustration when encountering the widespread mis-mappings of on-line to interactive and light-pen to graphical. We view the dissemination of the model and metric of interactive systems equal in importance to the continuing application of that knowledge in the ongoing research of the laboratory.

Bannister, D. and J.M. Mair, "The evaluation of personal constructs", London: Academic Press, (1968)

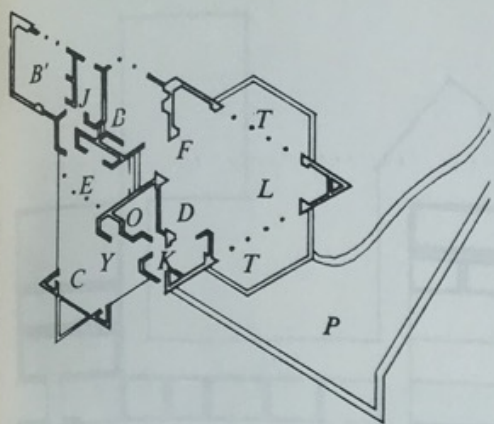
5.3.14 Transformations

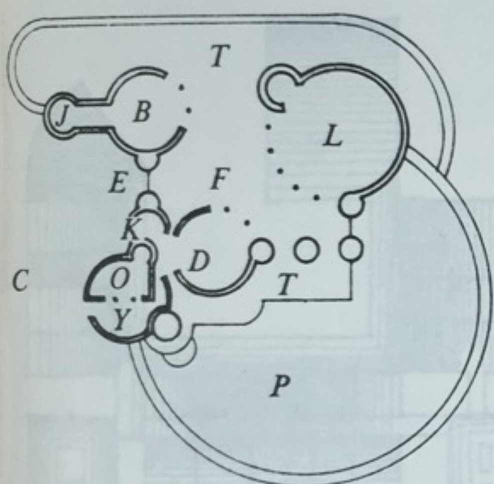
Part of our research during the past three years explored transformations of a very particular kind: transformations relating to communication emanating from man and intended for machine. In follow-up work, we will broaden the exploration of transformations to include those pertinent to communications between humans (interpersonal) and with self (intrapersonal).

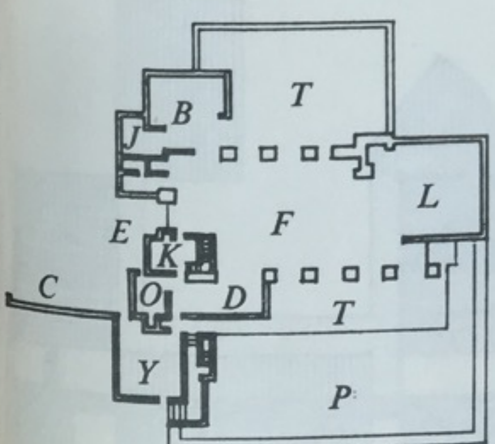
Our work in sketch recognition is described in the paper titled "Graphical Input Through Machine Recognition of Sketches," (Appendix X). A central feature of that work is the transformation of rough, sketch input into compact, machine compatible formats. The motivation behind the work is the desire to involve computers in the early stages of design, say for cost estimation, rather than waiting until the later stages when their capabilities could come too late. The result of this work involves recognizing intentions so as to transform tight, quickly drawn curves into corners, "jumpy" lines into straight lines, proximate end points into latched intersections, and so forth.

But there are reasons for transforming input in additional ways. Mediation, chapter 3.0, outlined benefits that can accrue from different forms of transformation. Clear communication of meaning between parties and with oneself is perhaps the most obvious and meaningful. And Exteriorization, subsection 1.4.5, pointed to studies documenting the power of individuals to draw associations from external representations. The theme of this and the following subsections is to broaden the range of potential transformation processes.

Yet in the face of these arguments, there remain sound reasons for maintaining representations in their original form. Regardless of the medium in which they are created, drawings and other forms of representation take on meaning







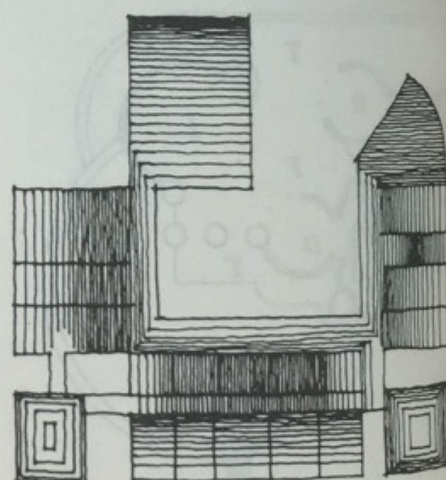
for the person creating them beyond the subjects at hand. A smudge may have content for its creator other than "closet here" or "swampy area." The smudge can provide visual recall of the draftsman's entire frame of mind at the time of the "smudging" -- that is, where he was, what his goal structure was, etc. If for no other reason than to maintain access to this gestalt, the original form of the representation should always be available.

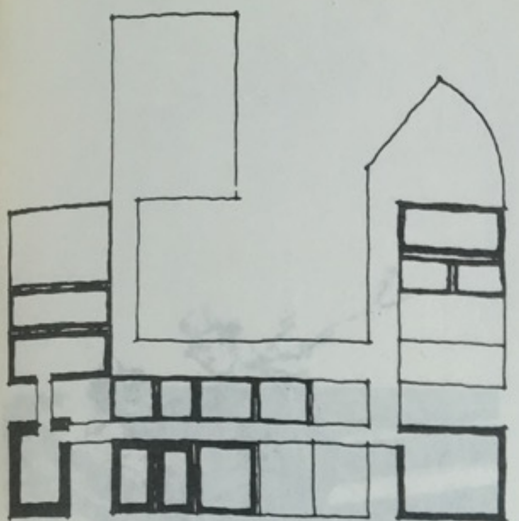
In some settings this conflict would give rise to a selection process -- determining how many people objected to losing their original work, etc. But given the "both/and" philosophy behind our research, we see no reason for not presenting both the original and *several* additional transformations, simultaneously.

We will develop a demonstration system using the hardware technology of large, flat screen displays (subsection 5.4.5) and the large-scale projection displays described in Seeing through Your Hand (subsection 5.3.11) to provide multiple representations simultaneously. Using displays as large as a desk top, it will be possible to "scatter" several variations of a drawing across a surface, much like an automated tack board. While facilitating extremely natural input, complete with smudges, algorithms will be developed that will transform the natural input to several other versions in view: a sharp-lined, rectangularised interpretation; a greatly simplified diagram; and perhaps even versions in the "hand" of others (Picasso, Giacometti, fellow workers).

Features of the transformation system will also enable the draftsman to "pull" any of the displayed variations to the "work's surface" either for reference or for continued input. In the latter case, he will be given the option of having his natural input continue to appear within the now displaced "original," or having it appear "superimposed" on the variation at hand.

(see Yellow Trace, following subsection). Alternatively, the natural input would continue to appear with the "original," while the properly transformed version appeared under his pen. He would be drawing as Picasso!





5.3.15 Tracing Paper

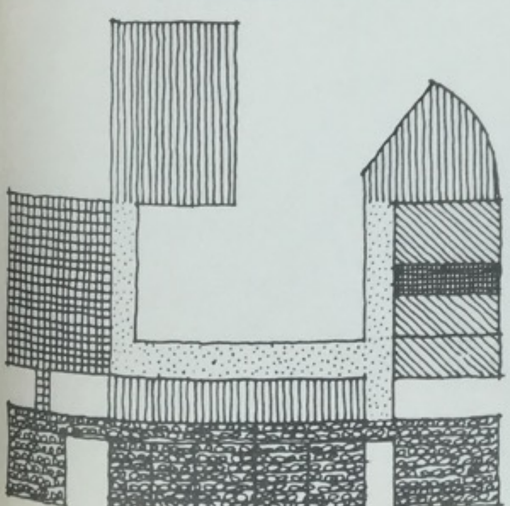
Most architecture students can recount feelings of shock and rejection when instructors had the audacity to mark upon their drawings. Similar fixations with the preservation of original works account for the presence of office copiers. "Books are our friends and must not be marked upon;" but a copied page or chapter is ours to do with as we will.

This phenomenon extends to authors as well. Many artists would explore more diverse variations of an idea were they not blocked by fears of irretrievably altering the original. To solve this dilemma, artists and designers have developed techniques for maintaining an original while exploring alternatives. Tracing paper is one of the most common, and with good reason. By laying a tracing sheet over previous representations, a designer can not only explore a new direction, he can work with the full context of his previous graphics to support his efforts. He need not lose the creative inspiration generated in the original. He can maintain a continuum throughout the evolution of an idea.

We will automate this conventional technique. In the process, we will explore the potential for machine mediation of variable opacity, layering, and regeneration.

Variable opacity will be implemented so as to permit a user to "defocus" an underlaying representation,

1. by dropping the intensity of overlayed features, not only on the basis of their depth, but also on the basis of their significance, where significance is inferred perhaps, from the number of redrawings per element
2. by blurring the overlayed image such that only its grossest features remain recognizable (see subsection 5.3.6, Caricature).



Layering, too, will explore both traditional and machine-augmented techniques. Obviously, we will enable the user to shuffle layers without x, y displacement. But capitalizing on the power of the machine, another feature will permit the user to specify "effective" levels by adjusting the intensity of images directly. This would be similar to dimming the lights on some sheets, raising them on others.

A side issue in this regard is the means for identifying layers and recalling past images from the stack. Numbering is the obvious approach and will, of course, be implemented. Others include "flipping" through the stack (note the proximity to animation) and recalling images with shared graphical elements ("Let me see all the figures with red and blue checkers").

Conventional tracing procedures require that the draftsman "fill in" the unchanged portions of an image or attach it in some way to its underlayer. In the proposed tracing system, it would not be necessary to redraw the entire image, only those portions being changed. Notified or inferring that no further changes are forthcoming, this implementation will perform an intersection of the two states and regenerate the remainder -- the unmodified portions -- of the drawing.

5.3.16 Painting Photographs

A customary distinction between a drawing and a photograph is that one is executed by hand and the other by an apparatus. This task of our proposed work removes that distinction by allowing for an interactive facility for three-dimensional photomontage. This is akin to the recent work published by Blinn and Newell "Texture and Reflection in Computer Generated Images."

Painting photographs would be achieved by storing "front-on" views of real textures. For example, consider a brick wall stored in an n-bit ($6 < n < 18$) per point frame buffer image of it as if it were perpendicular to the observer's line of sight. Subsequently, if a brick wall were to be the containment or texture of a shape (subsection 5.3.2, Shape-Oriented Graphics Language) not perpendicular to the line of sight, namely receding in perspective or in axonometric skew, the bits could be properly computerized and compressed to portray accurately "brickness" seen at that angle. This can be extended to any plane (not necessarily flat) at any attitude, if the original image is front-on. In theory, any original image can be used (as map-makers know) if direction and focal length of camera are known, but this would cause a fuzziness in the image when expanded into a more front-on shape.

This would work in the following manner: a television camera would be used to read in color photographs of front-on textures (like brick, grass, wood grain, fabric, concrete, etc.) either in terms of three components, red-green-blue, or in terms of a luminance and two values of chrominance. These would live on disk.

The user, in a video-based computer graphics environment, not unlike our current "PAINT" (subsection 5.1.2, Complex Displays) would be able to give his stylus (subsection 5.3.3, The Intelligent Pen) the attribute of brickness. What would be significantly different than "PAINT" is that the boundaries would be 3-D delimitations. Flood mode would exude brick, for example, with faithful and accurate perspective.

Architecturally, this can be likened to a rendering, but with photographic detail. Even if the whole picture did not receive "picture flooding," the illusion of realism would be startling. This is not unlike the observation of Professor Donald Appleyard and his colleagues at Berkeley. They have noted that simple pictorial cues, like a Coca Cola sign or doorway, enhance an otherwise barren cardboard model with uncanny impact, far beyond the paucity of their area coverage and its proportion to the whole model.

Besides the development of a stunning aid and substitute to rendering, we see the implementation of painting a photograph as an important part of and incentive for graphical conversation. Intrapersonal communication would enjoy a dimension of previsualization, for which we have no precedent. Architecture-by-yourself (Appendix X) would serve as an excellent example. The designer homeowners could get photographic quality and magazine-like representations of environments that not only do not exist, but are still in their early stages of conception.

5.3.17 Personalizing the Screen

Personalization, section 3.2, notes that "Even the commonplace profiles of time sharing do not invade the format of displays." Worse still, even our own applications have very little to show (pun intended) in the area of personalization. Two of the architectural applications point in that direction by placing the various menus to the right or the left of the screen depending on the user's handedness. Beyond that, the most personal screen organizations are accomplished by students, who in their class projects consistently frame each conceptually separate element in its own little box; at least these formats are created to meet the approval of their most intensive users, the students themselves.

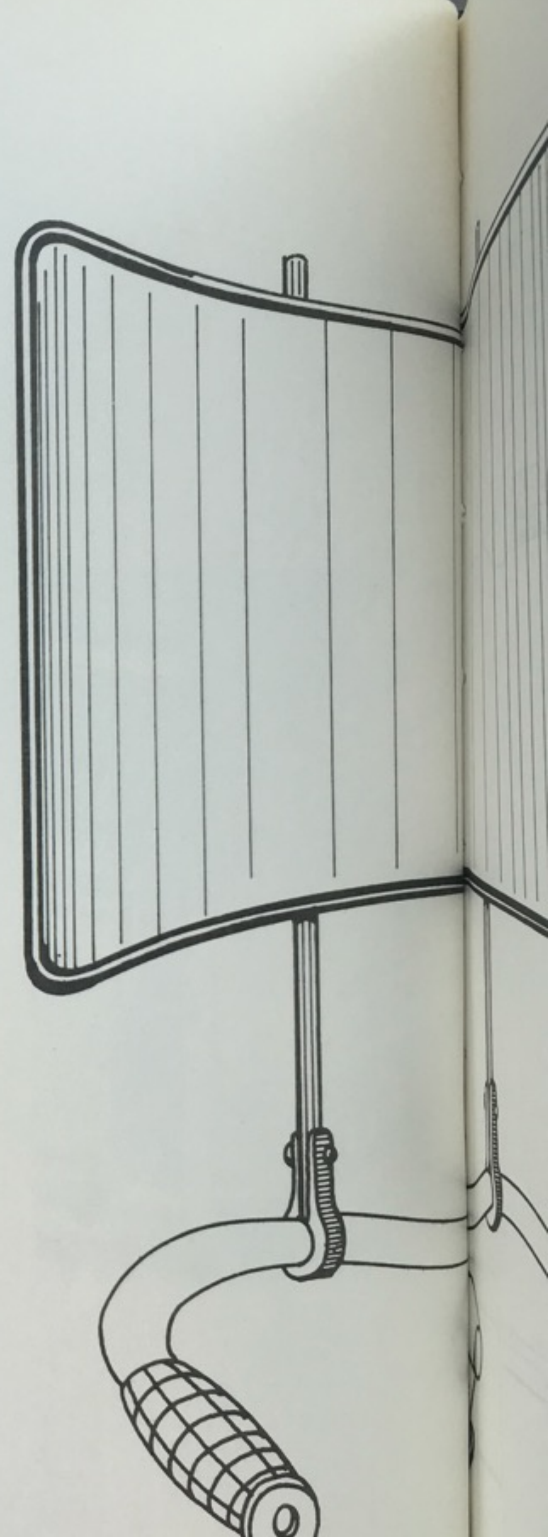
We propose here both specific tasks and a general theme. Specifically, we will implement techniques enabling users to format their displays to suit their own needs. These will include being able to move menus off the screen when not in use and to "pull" them back again when desired -- to place them specifically or carelessly, to place them appropriate to the task at hand. For example, if a user is typing extensively while indicating certain elements on the screen, this feature would permit placement of those elements near the keyboard to minimize hand displacement.

Our experience in this area indicates that naive users are interested both in a variety of display capabilities and in the techniques for calling them forth. "Can I see that in perspective? How do I do that?" are typical queries. We will explore techniques to make these questions self-answerable. One of the more obvious of these is to let the person define commands as gestures (subsection 5.3.4).

Controlling the quantity of information on the screen is another factor amenable to personalization. The simplest approach to this is to allow each party to erase the screen when desired. This could be accomplished in a variety of ways determined by personal preferences. It may occur as a function of the level of activity (interest) demonstrated by each party ("When I am working away, give me a clean slate," or "Clear it off if I haven't done anything for a while. That will jog me back to the present"). Alternatively a user may wish nothing to disappear suddenly, but would have elements gradually fade (or become less detailed) as they were ignored.

Erasure will obviously be done on different bases by different people. In a conversation, then, it is entirely possible that one person might refer to an image eradicated on the other person's screen. In this case the second person may wish to see that element or even the entire state of the display at the time the element was erased.

These examples are given not as specific tasks to be implemented, but to indicate erasure, recall, brightness, size of image, detail of image, as well as sound, intermittence (blinking), and timing are display features amenable to personal modulation. Our work will explore the potentials of this theme and implement a variety of capabilities beyond simple demonstrations to enable actual graphical conversations with personalized displays.

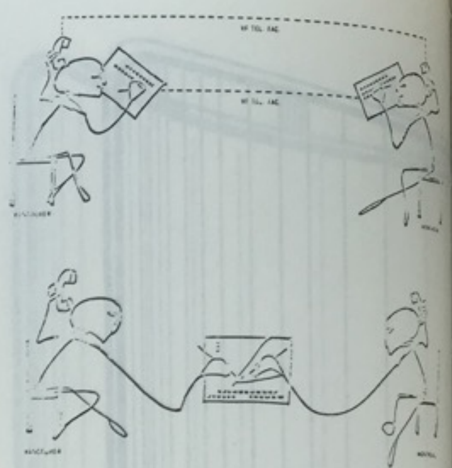


5.4 Hardware Landmarks

The following seven subsections are in this chapter on Tasks because they form essential ingredients to our future as well as past work (subsection 5.1.5, Hardware). They should not be read as undertakings of the same nature as the previous seventeen projects and themes. While we fully intend to do the kind of work that will directly or indirectly affect the development of these *machines*, we do not claim to be designing new hardware. In some cases we are simply lining up to get first releases and prototypes of that kind of equipment we feel to be essential to the future of interactive graphics. Our list is in no sense exhaustive.

The term landmarks is used also to connote prognostication in industrial development as we see it. In many cases we gain our perspective from individuals in industry and government with whom we work intimately, who visit us occasionally, or who have done as little as correspond. Companies of particular importance to us are listed to the side.

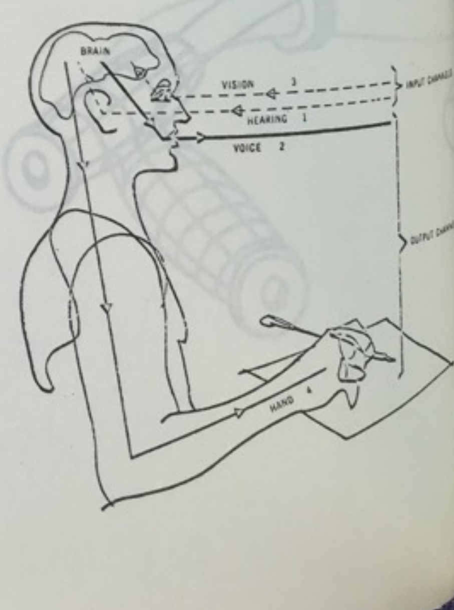
5.4.1 Scribblephone



Scribblephone (TM) introduces our section on hardware landmarks because it is unequivocally the most germane, existing piece of telecommunication hardware. The early concepts of Thompson and Westelman were precisely those of shared graphical spaces. In 1968, they asked, "Is it possible to create an environment such that two people, remote from one another, could jointly and simultaneously create a single sketch, visible to both parties?"

Today we find a prototype Scribblephone at Bell Northern Research (BNR) in Canada. BNR follows and supports our current work (see subsection 8.2.2). In connection with this proposal, we are asking them to consider placing two Scribblephones at MIT for the beginning period of our study. We shall describe its salient differences to commonly known products or projects; we feel uncomfortable describing its particular functions and techniques at this writing, being unfamiliar with the proprietary issues surrounding the device.

Visual Electronic Remote Blackboard (VERB) is a telecommunication proposal for one-way communication to be used in applications akin to the most parochial teaching methods. A two-way VERB approximates a Scribblephone, but is different as long as it remains a relative of the Picturephone, where each party has an individual view of the "scene." Only when that view is the same, as in the adjacent figure, does the Scribblephone achieve its unique quality of shared space.



Current implementation plans for Scribblephone include only modest computer mediation, mostly for overcoming bandwidth limitation. Mediations of the sort described in chapter 3.0 are advanced applications to which we would apply the device.

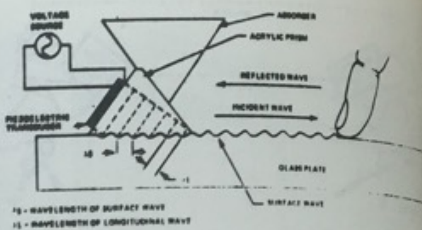
5.4.2 Touch Sensing

Touch sensitive systems are input media with a passive stylus. The excitment of these devices lies in their ability to provide the most natural input path to the computer. The umbilical cord attached to normal tablet pens is gone, and everything including fingers and hands can be used to input graphical data.

However, these systems fail to realize their potential because of several mechanical and electrical shortcomings. They are capable of resolving only *one* finger or pen placed on the active surface at a time, and they have no near-field sensitivity. As a consequence of the first disadvantage, the user may not rest his hand on the surface while using it, and thus the device is no longer a natural input system. As a result of the second, no cursor can track until a touch is made, and the distinction between locating a point and indicating that point is lost.

Past implementations of touch sensitive tablets have used either an array of switches under a plastic surface (Litton Industries), or a set of light beams and photodetectors along the edges (Plato, Magnavox display). Resolution is on the order of two points per inch, thus limiting their use to simple menu selection devices, or keyboard replacements. They are usually incorporated into an active display of some kind. In the Litton version, for example, the wires are thin enough to be virtually invisible and are placed over the surface of a light-emitting diode panel capable of displaying characters of simple graphic symbols. The system, used as a hand-held keyboard is a controller for a large-screen tactical military display. In the Magnavox terminal, the display is a plasma panel built into a hood to allow simultaneous presentation of slides and computer graphics. The touch panel is used as a pointer -- a light pen substitute.

More recently, a true graphics tablet has become available. This device, built by Instronics, works on the principle of transmitting surface waves across a transparent sheet of glass and ranging their reflection along two orthogonal axes. This tablet is capable of resolving 100 points per inch and data rates of up to 100 digitizations per second. Because the glass can be curved, the tablet can be manufactured directly onto the surface of a standard CRT display. We have this system in our laboratory and are experimenting with ways to improve its characteristics (Appendix IX).



Future investigations of touch sensing will take entirely new approaches. We believe that the idea of trying to locate objects on the surface by looking from the edge is inherently limited and readily leads to ambiguities. The touch sensor could be a vidicon camera looking through the rear of a "peek-a-boo" CRT tube. This tube could have a transparent phosphor, and since it is looking straight at the surface, could detect multiple fingers, and even areas, unambiguously. We have also suggested pressure-sensing surfaces. This is analogous to placing a trackball on the face of the display on strain gauge mounts. This tablet is not intended to detect position of fingers or hands, but force, both transverse and rotational.

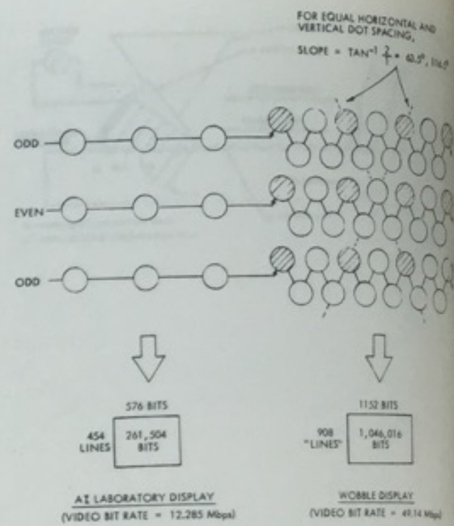
5.4.3 1000 Line Color

The advantages of television-type displays in computer graphics has been amply discussed (Appendix VI). In the case of normal-sized black and white images, Xerox has demonstrated an 875-line system (the ALTO), where the line structure of the TV image is invisible. For color presentations, there are two problems: bandwidth and CRT resolution.

Normal direct-view CRT's that can display full color (beam penetration types excluded) use the shadow mask construction, thus limiting the resolution to the number of primary color triads along a scanning line. Historically, tube manufacturers have addressed themselves to the problem of color phosphor chemistry to improve hue and temporal resolution, and the spatial resolution has remained constant at approximately 320 lines. Now that the application of color CRT's is expanding beyond normal home TV, higher resolution tubes are becoming available: from RCA, a tube with 18-mil spot centers, and from Mitsubishi, a tube with 13-mil spot centers. This tube can therefore display 640 lines, but has not yet been incorporated into a monitor that can run at 1000 lines. Incorporating these new tubes into high-resolution monitors still requires solving both the bandwidth problems inherent in scanning at that rate, and the convergence difficulties.

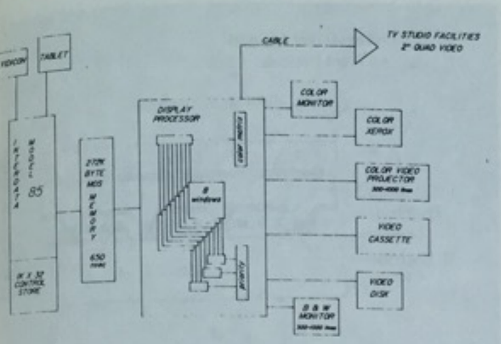
In the case of projection displays, one can use three black and white tubes with filters or colored phosphors, one per primary, and converge the images on the projection screen. This avoids the problem of shadow mask construction, but adds a problem of registration. To date, no acceptable 1000-line color projection system has been demonstrated. At this writing, we have a General Electric light valve projection television display in our laboratory. GE will offer the 1000-line capability through a single lens in the future, hence avoiding the issue of registration on the screen.

Clearly, after the 1000-line problem is solved, the next question is how to attain the yet higher resolutions necessary for large-scale displays. John Ward has investigated beam wobbling techniques in which the electron beam of a standard CRT is oscillated vertically as it sweeps across the screen by a modulator in the vertical deflection circuitry. By appropriately presenting the data, the system has effective 1000-line resolution: it writes alternate picture elements on two lines. This system has the advantage that the display is coherent when presented on a monitor without the vertical wobble circuitry in it.



Comparison of Standard and Wobbled 525-line Rasters

Ward, John, "Wobbled-raster high-resolution display", MIT, Project MAC memo 431, March, (1974)



5.4.4 Future Frame Buffers

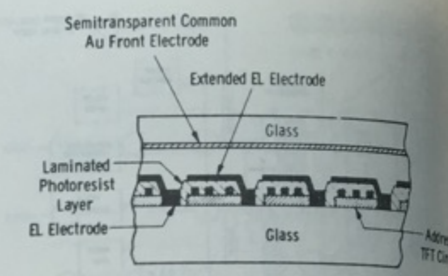
As the resolution of a raster scan display goes up, the size of the memory necessary to buffer the refresh image increases as the square of the linear dimension. Notwithstanding the fact that memory costs are dropping rapidly, and new technologies are arriving that make large-frame-store memories economically feasible, research into buffering techniques and management techniques is necessary.

The earliest methods used to minimize buffer requirements were scan conversion, either in hardware, as in the case of storage tube scan converters, or in software, brought to its highest level of development in the Navy's Proteus display. This system includes real-time generators for characters, vectors, conics, and several application specific displays like A-Traces and Waterfall displays. It is capable of rendering only single-tone images. In hardware, the Princeton Electronics and Hughes storage tube converters can display several gray tones and include the ability to erase selectively.

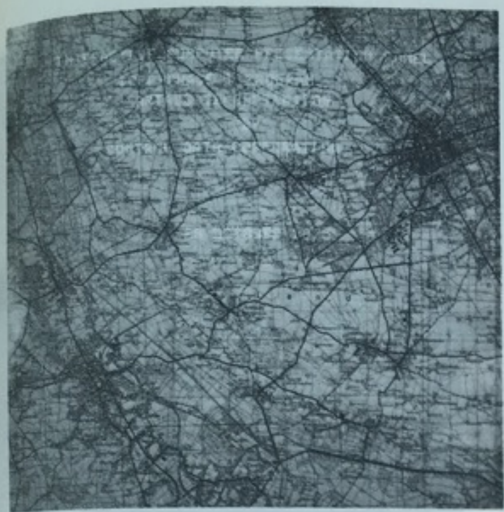
Later methods use statistical encoding to reduce storage and allow a variable number of bits per point to be stored, depending on image complexity. This technique lends itself readily to multiple gray-tone and color displays, but is only efficient for images such as characters and vectors whose complexity is known in advance. In this case, statistical encoding degenerates into run-length lists.

It is becoming increasingly clear that coding techniques on random images do not ultimately save buffer space, and suffer from difficult access and process. In addition, since they have less redundancy in the stored image, errors tend to show up. Thus, more emphasis is being placed on explicit, bit-per-point displays.

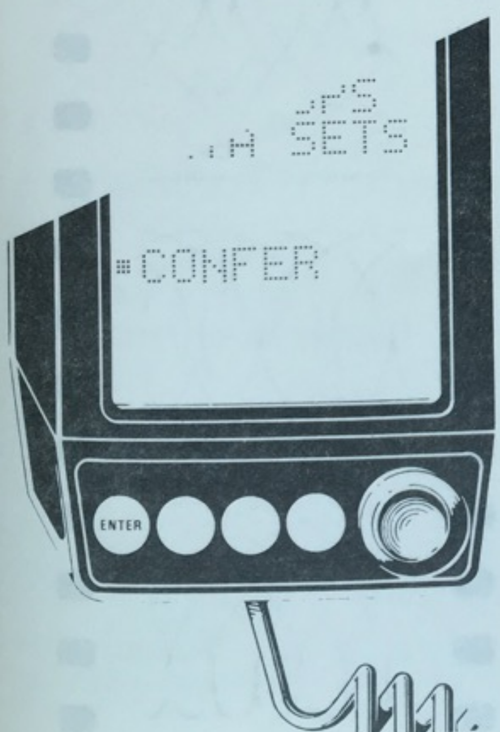
Development areas for these displays lie both in the device design area -- CCD's and bubble memories -- and in management techniques -- addressing and access schemes. This allows rapid access to the mammoth amounts of data required for explicit, multi-colored, high-resolution display systems. Research into displays with memory incorporated into the display media are also in progress, most notably, the thin-film transistor displays being developed at Westinghouse by Peter Brody (see subsection 5.4.5, Flat Displays).



Cross-sectional view of an EL panel with extended electrodes.



Four foot square transparent
plasma panel developed by
Control Data Corp.



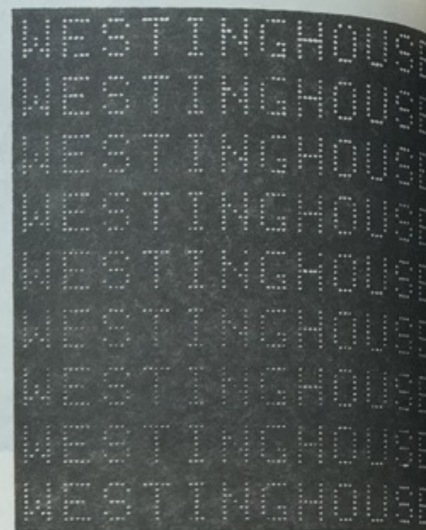
5.4.5 Flat Displays

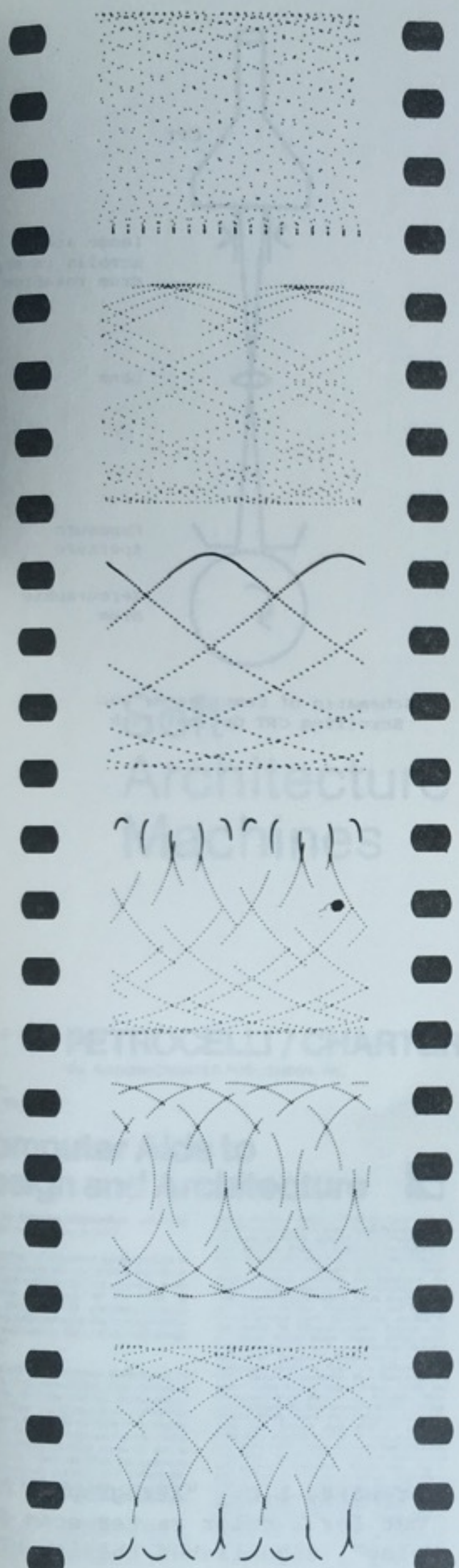
Flat displays offer a panacea for many of the ills of current output technologies. They are smaller, less cumbersome, have the capability of including their own memory, and can be integrated into a system complete with tablet input. Their only problem is that they are not quite here yet. However, there is much current research with immediate promise.

The first flat display to become readily available was the plasma tube. These displays have limited resolution and no gray scale or color capabilities, but include the memory in the display. Control Data has demonstrated tubes that are four feet on a side, include a scanning feature that allows their use with a light pen, and have 22-line-per-inch resolution making them comparable to a 1000-line TV system. They have also demonstrated smaller tubes with resolutions of 60 lines per inch, and have the technology to build displays that run at 100 lines per inch in the near future. These will be limited in size at first, and will grow as fabrication techniques improve. There is no read-out capability in them, and thus a representation of the image must be stored in the computer memory.

Litton Industries has also demonstrated large scale displays using LED technology, with 22-line-per-inch resolution, but also capable of displaying limited color rendition and architecturally capable of generating continuous tone and full color images. These displays are the modern analogue of a large array of very tiny light bulbs, and consist of a hybrid module with the driver circuitry and memory on the back and the LED's integrated onto the front. By making the hybrid module increasingly complex, one can add more color and gray scale capabilities, as well as read-back. Thus far, they are limited in hue representation by the available LED technologies, and in brightness by the power consumption of the relatively inefficient LED device.

The most promising area for displays is the thin-film transistor display, being studied by Peter Brody of Westinghouse. This uses thin-film deposition techniques to deposit a memory cell and driver electronics on a sheet of glass, and to overlay various display media on top. The medium can be light modulating liquid crystals, or light generating electroluminescent phosphors. Electro-luminescent chemical research is at a high level, and color displays can therefore be generated. This type of display system also makes use of manufacturing techniques well within the range of realizability. Circuitry for addressing a high resolution display can be integrated onto the edge, solving the problem of multiple connections. The thin-film technology also allows for arbitrary circuitry to be added to the system, allowing a tablet to be integrated onto the surface of the display.





5.4.6 Write-once Memory

The concept of write-once memory is not new. When instrumented in the small scale sense of "blowing ROMs," the notion is of reading well-formed information, usually procedural, rarely data. In the larger scale, for example, a trillion bits, the concept is closer to random access, read-write in the sense that there is so much space available that you can throw it away as it gets used up. Very few applications are inherently write-once.

It is included as a hardware landmark because digital video is precisely a write-once application. A trillion bits can store almost three hours of live video, without imaginative encoding. We see this as an important component to computer animation, especially when the fiche (or whatever format of whatever medium) is inexpensive enough to be used like movie film. Movie film is, after all, the epitome of write-once memory.

We are currently pursuing write-once technologies in concert with Conversation Video (subsection 8.3.3). At this time we are close to the work of Precision Instruments (California) and their terabit store. It is a rhodium plated precision mylar system of strips, written by laser. The capacity of the system (10^{12} bits) is achieved with 640 strips, each roughly 4 inches by 3 feet.

5.4.7 Color Hardcopy

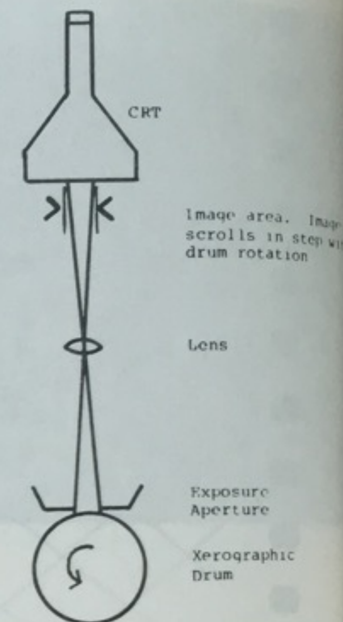
The aim of any hardcopy system is to provide essentially free and immediate results of any interaction for use while the interaction is still in progress (or current). In the past, this was accomplished by using plotters and Polaroid photographs. With the arrival of raster scan displays, capable of displaying areas and solids, plotters no longer sufficed. Polaroid photography, while fast, creates prints that are out of scale with the display and whose costs are prohibitive. This is especially true for color displays.

The advent of Xerox's halftone and 3M's continuous tone color copiers removed this limitation making the hardcopy immediately available. Research into methods to interface these machines to computer graphics systems is ongoing both here and at Xerox. 3M has discontinued their line. Several Japanese companies are also entering the color copy market.

Depending on the resolution required, various optical paths into the machine are used. Lasers have been proposed and can produce greater than 1000-line resolution across the page. These systems approach the limiting resolution of the Xerox optics itself.

Work here has centered on integrating the output with the graphics system itself and has stressed the immediacy rather than the resolution of the output. CRT technology is used, and the system runs as an adjunct to the raster scan system.

Further research is directed towards gray tone and full color representations. The ultimate aim is for the hard copy to be an instant, accurate representation of the interaction in progress.



Schematic of Compressed Scan
Scrolling CRT Optical Path

Stewart, L.C., "Xerographic output for a color raster scan display", unpublished thesis, MIT, (1976)

5.5 Dissemination of Results

In October 1972 the Architecture Machine received its first major NSF support. It was $100,000 (a few dollars less) for one year. The short duration was in part probationary. We had been reprimanded for not disseminating our results properly, prolifically, and punctually. The following year, in June 1973, "Recent Advances in Sketch Recognition" won the AFIPS award for best technical paper. These past three years, we have swung in the other direction perhaps too far, making our work highly visible.

The next two subsections dwell on formal and informal plans for disseminating results, not including books. They enumerate a typical agenda of refereed and nonrefereed papers and a not-so-typical newsletter scenario.

Books are another matter. In the past twelve months both *Soft Architecture Machines* and the anthology *Computer Aids to Design and Architecture* have appeared. The first was written in the summer of 1972 (!!) by the Principal Investigator. The second was edited by him in the summer of 1973 (not much better publishing speed) and includes two NSF/Architecture Machine participants: James Taggart (who has since gone to Applicon and leads their 3-D work) and Guy Weinzapfel (whose curriculum vitae is found in subsection 7.1.7 and whose continued interest is found in subsection 8.3.1).

Careful review of the Schedule (section 5.2) reveals an item called "book," without further specification. This item comes at the end of the third year, with the intention of providing that which we have heard called for at several recent meetings: principles of interactive graphics. While the title has been used, the topic is not covered in the wide-ranging sense that we have used the term "conversation theory." Without predesigning this text, we submit that it will be a joint venture of the staff on the project, conceivably co-authored by the same or as many people as this proposal. One notes the time it takes to assemble a proposal of this size and recognizes that double or triple the effort could be distilled into a book a half or a third the size.

5.5.1 Publication Schedule and Plans

A five-year schedule is not possible without the clairvoyance that reveals planned conferences, special issues, or anthologies. SIGGRAPH occurs each year, but lacks the scholarly rigor with which a mathematician, for example, finds comfort. Special workshops, like ACM's recent "User-Oriented Design" are unpredictable. And IFIPS is too frequently weighed down by national equities inherent in their charter.

It is interesting to note that this coming summer the computer graphics conference, a cybernetics conference, the artificial intelligence conference, and the IFIPS meeting, all one week long, take place within a six-week period! We plan to actively participate in all of them (Appendix VII, "On Being Creative Using CAD" is a draft of the invited, keynote paper for the CAD and Graphics sessions on the topic). The AI Conference is, in fact, at MIT.

Of special interest is the March 1978 IFIPS seminar, "Artificial Intelligence and Pattern Recognition in Computer-Aided Design."

Mention should also be made of internally generated meetings, such as MIT Summer Sessions and Industrial Liaison Symposia. The former is a tutorial session, usually limited to 20 or 30 paricipants, who in the past have returned to teaching situations. The latter is a more recent activity which attracts over two hundred participants. The following pages are a reprint of the recent sumposium on Computer Graphics, held on November 23, 1976, coincident with the production of this proposal.

5.5.2 *Machinations* Continues

Normally this section would not appear. However, we have struggled with our newsletter, *Architecture Machinations*, and wish to share the vacillations and to invite criticsm. With a firmer understanding (over one year after its inception), we would like to encourage other research groups to do the same and to persuade NSF that it is a legitimate and forceful research enterprise, to which a small chunk of this budget should be applied. At this writing, no NSF funds are devoted to *Machinations*.

Machinations is a weekly rag for internal communication. It usually averages twenty pages. Its contents range from preprints, to informal reviews and trip reports, to local changes in the hardware and operating system, to a calendar of our week. One hundred copies are printed.

A few of these slipped out the door last fall. Some went to industrial sponsors, some to program directors, in federal agencies, and some to friends and colleagues. This has grown to the point that 45 copies leave the walls of MIT.

Much benefit accrues from the copies that travel through the U.S. mail. Calls with references, pointers to new inventions, or probing questions frequently come. It gives "glue" to the day-to-day and week-to-week atmosphere of our laboratory. Students are inspried to write intentions down before they code them. Staff can issue provoking ideas. And so on. The newsletter is not *edited* in the sense of what goes in and what does not.

We propose to continue this venture. We use College Work Study Program monies to produce it on the 80 percent matching basis. Consequently our weekly labor cost is less than 7 dollars. The printing averages 25 cents per copy, the postage, 13 cents.

ARCHITECTURE MACHINATIONS

A weekly newsletter of the Architecture Machine Group, Department of Architecture, M.I.T., Room 9-518, Lee Nason, editor.

We propose to use 50 dollars per week of this NSF budget for *Machinations*. The cost is low. We submit that the value of the idea is high and encourage other NSF-sponsored projects to do the same.

6.0 HYPOTHESIS TESTING

6.0 HYPOTHESIS TESTING

Beyond enabling expressive capacity in the graphical modality, we have some questions in mind about how human users will interact with an augmented computer-based facility serving as a matrix for graphical conversation. A number of hypotheses of interest will serve as leitmotifs, as *leading questions*, throughout our exploration of graphical conversation. These themes will occur and re-occur throughout the life of the project and will find expression, and receive evaluation, in many contexts.

One braod class of hypotheses have to do with differences in cognitive style across and within individuals. Distinctive strategies have been observed, for example, regarding the ways people will record the different qualities of a set of observed objects.

Haber, R.N., "Nature of the effect of set on perception", Psychological Review, 73, (1966), pp. 335-351

In this regard, Haber (1966) has divided subjects into two broad classes: "Object Encoders," who seem to organize lists of properties of an object about that object, and "Dimension Encoders," who apparently prefer to list the different values various objects may exhibit with regard to properties of interest.

Pask, G., "Learning strategies and individual competence", Report on SSRC Grant HR 983/1: System Research, Ltd., (1971)

In a similar vein, Pask (1971) has discovered two general cognitive styles that separate learners into two groupings: "serialists," and"wholists." A wide variety of information was made available to subject learners about an imaginary biological taxonomy of animals to be found on the planet Mars. The sequence by which subjects examined the information was recorded, and subjects were subsequently asked to explain the taxonomy to the experimenter. Objective measurements showed a bifurcation in basic styles and strategies of learning. "Serialists" dealt with one taxonomic feature at a time, and proceeded to create lists of animals having that feature. In contrast, "wholists" considered the entire set of subspecies, and for each subspecies attempted to draw out the distinguishing characteristics. In follow-up studies, Pask found that when teaching-machine protocols were drawn up for either learning strategy, performance in learning was better if a "serialist" subject was matched with a "serialist" program and if a"wholist" individual was coupled with a"wholist" machine protocol than if a stylistic cross-coupling of person and program were employed.

Accordingly, we expect that in graphical conversations, as appears to be the case with well-defined, though not specifically graphical conversations (Cf. section 1.2, Conversation Theory), strategic differences will be exhibited. It is further hypothesized that differences in strategy occurring in "strict" conversation heavily loaded on *graphical* modalities will be carried over into the non-strict phases of the conversational exchange.

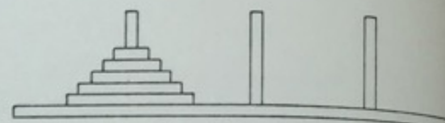
Thus, in a non-strict conversation, people don't stick to strategies, but exhibit shifts in strategies. Of interest, then, will be the consequences for strategic differences in graphical conversations when the boundaries between the strict and non-strict conversational phases are crossed. Hypotheses are:

1. Some strategic differences will be exhibited in strict conversations.
2. Locally, where the graphic conversation becomes strict due to constraints imposed by the "teacher," then strategies are exhibited.
3. Upon the transition from the strict to non-strict phases, only surface "stylistic" differences will remain, rather than deep strategic differences.
4. None of the above occur (null hypothesis).

We would not be surprised, in fact we hypothesize that the intersection of graphic presentational protocols embedded in machines will interact with strategic proclivities in and among users. Further, the dynamics of this interaction may well be further modulated by subject matter, context, phase of the interchange (early, middle, late), and yet other variables. Imagine, for example, a broad cleavage among individuals into "visualizers" and "verbalizers." Surely such a dichotomy in cognitive style should interact with the relative graphical versus verbal loadings of the ongoing dialogue, and, further, interact with subject matter. Consider a dialogue about specifically visual matters such as 3-D visualization puzzles, as opposed to inherently non-visual puzzles (a logical derivation or numerical puzzle). Or, consider a problem-solving task with constituents that could be presented graphically under one condition, and verbally under another condition. It is known that the form of representation of a problem strongly influences the probability and the time course of solution. The provision of graphic facilities should have a beneficial effect in computer-aided problem-solving activity and computer-aided learning.

Schwartz, S.H., "Modes of representation and problem solving: well-evolved is half solved", Journal of Experimental Psychology, 91, (1971), pp. 347-350

An exemplar of a learning and performance task upon which the selective effects of graphical presentation and tutorial interchange might have significant effects is the "Tower of Hanoi" puzzle. The puzzle, a well-known classic, consists of a small, flat rectangular board, upon which are set three upright dowels or pegs. A variable number of wooden disks, each with a hole drilled through its center are stacked on one of the end-pegs of the board. The disks are each of a different diameter, and are stacked on the beginning peg in decreasing order of diameter. The appearance of the little pile of disks is vaguely pagoda-like; hence, the name of the puzzle. The object of the puzzle is to move the entire pile of disks from one end peg to the other, moving one disk at a time. Any move consists of taking a disk off of a peg and moving it to a peg where there is either no disk, or where the topmost disk is *larger* than the disk just about to be placed upon it. No other moves are permitted.



The Tower of Hanoi Puzzle.

The "Tower of Hanoi" is an example of a sequential task involving transitional states of knowledge converging toward a solution, and has been studied extensively in order to map changes and shifts in strategy among populations of subject problem solvers. A not dissimilar problem is the "Hobbits-Orcs" puzzle. This puzzle requires the subject to produce a series of moves that transport three Hobbits and three Orcs across a river. Hobbits are gentle, kind creatures (in J.R.R. Tolkien's renowned "Middle-Earth" Trilogy), and Orcs are nasty, fearful creatures. The only means of transportation across the river is a boat that can hold one or two creatures at a time, with at least one creature needed to row the boat during any crossing. The chief constraint is that at no time can there by one or two Hobbits on either side who are outnumbered by Orcs, since if the Hobbits are outnumbered, however briefly, the Orcs will gang up and devour them. Like the "Tower of Hanoi" puzzle, this paradigm is being used to uncover subject problem-solving strategy and behavior under varied conditions.

The relevance of these puzzles to our efforts is that these are puzzles about which a great deal is beginning to be known, especially how, as sets of goals and constraints, they interact with strategies that subject problem solvers may adopt. And, they lend themselves very well to both graphical presentation and representation. But they can also be represented by simple symbolic notation. Accordingly, the form of representation of the problem can be studied as it interacts with styles and strategies of solution, shifts in strategy, ratio of graphical "hints" to non-graphical "hints," and other variables of interest.

Simon, H.A., "The functional equivalence of problem solving skills", Cognitive Psychology, (1975), pp. 268-288

Luger, G.F., "The use of the state space to record the behavioral effects of subproblems and symmetries in the Tower of Hanoi problem", International Journal of Man-Machine Studies, 8, (1976), 411-421

Simon, H.A. and S.K. Reed, "Modeling strategy shifts in a problem-solving task", Cognitive Psychology, 8, (1976), pp. 86-97

Thomas, J.C., Jr., "An analysis of behavior in the hobbits-orcs problem", Cognitive Psychology, 6, (1974), pp. 257-269

Greeno, J.G., "Hobbits and orcs: acquisition of a sequential concept", Cognitive Psychology, 6, (1974), pp. 270-292

Another domain of hypotheses involves the appearance and disappearance of awareness on the part of people of how they manage to do some task, or perform some skill. It has been averred that the explicit awareness of how one accomplishes something attenuates and drops out as learning and subject mastery progress. We hypothesize that this effect should also be manifest in instances of graphical conversation. The basis of this prediction is that the learner becomes aware of so many variants of accomplishing some act that the original "phrasing," quite self-conscious originally, drops out. Consider the example of learning a golf swing or a tennis stroke. Early on, one is told in so many words, as well as being shown, exactly what to do, in what sequence, and so forth. Upon any occasion of rehearsal, the act of execution is never exactly the same as upon any prior occasion. Amid the growing profusion of motoric variants on the same theme, the original (and highly verbally loaded) pattern goes away. Articulate incompetence gives way to inarticulate competence.

Bartlett, F.C., "Remembering: a study in experimental and social psychology", London: Cambridge University Press, (1932)

The durability of an *understanding* in conversations is one of our concerns (Cf. section 1.2, Conversation Theory). The issue here is how well a subject can re-construct an understanding. We hypothesize that, particularly with *interrupted* conversations, re-construction is possible (the so-called Zeigarnik effect). The effect upon a graphical conversation of un-coupled or changed goals will be examined, as in the case where an ongoing task is interrupted or deflected, and where a return to the former task may or may not be allowed.

Further, the course of learning as a conversation proceeds represents another line of inquiry in conversation theory. *Comprehension*, or the appreciation of global rules should benefit from the externalization, the making explicit by rendering visible, that a graphical medium for intellectual activity affords.

Similarly, *operations*, or the appreciation of local rules, are made manifest.

We look for the interaction of the visual/verbal dimension with the operations/comprehension (local versus global rules) dimension. *Versitility* would be the ability to combine and properly orchestrate local and global rules. Additionally, in any nontrivial *graphical* context, the ability of the user to perceive accurately figure-ground relationships is vital. It may be of some practical and theoretical importance to examine user performance and behavior in the light of the gestalt concept of "field-dependence."

These hypotheses give a sampling of what we will be exploring apropos of cognitive interaction of the user with a computer-based, *graphical* conversation facility. We expect further hypotheses and leading questions to emerge as our effort proceeds. An expected result of our concern with human factors issues are procedures and methods that contemplate human capacities as well as machine capacities, and the interaction of the two. Beyond this, we expect to advance appreciably the body of knowledge concerning the possibilities and limitations of man-machine graphical interaction.

McCulloch, W.S., "Embodiments of mind", Cambridge, Mass.: MIT Press, (1965)

Arbib, M.A., "Brains, machines and mathematics", New York: McGraw-Hill, (1964)

Zeigarnik, B., "On finished and unfinished tasks", in "A source book of gestalt psychology", Ellis (ed.), New York: Harcourt, Brace & World, translation, (1938), pp. 300-314

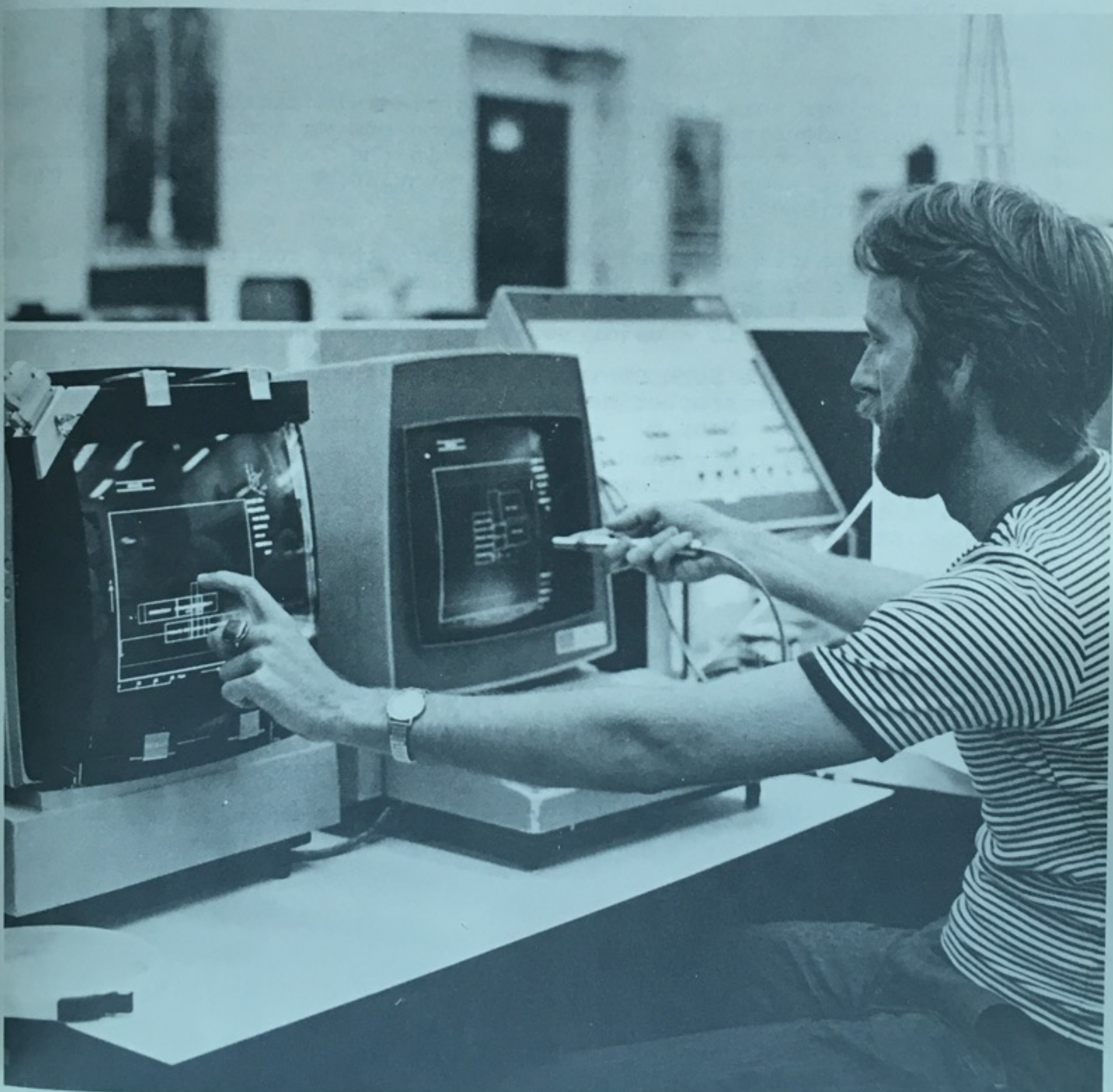
Witkin, H., et al., "Individual differences in the ease of perception of embedded figures", Journal of Personality, 19, (1950), pp. 1-15

7.0 FACILITIES

7.0 FACILITIES

Now we begin with the gray pages, primarily devoted to sharing with readers unfamiliar with us or our project those features of our research environment that distinguish it from other settings. The reader familiar with us can pass on to the budget (Chapter 9), with the exception of noticing the existence of subsection 7.2.2, Ph.D. Concentration in Computer Graphics.

Our perception of ourselves is that of a center of competence cutting across all departments at MIT, even though physically and administratively we live in the School of Architecture and Planning. The following sections may give an unjustified impression of scale, because some staff are supported through general funds and some projects are supplemented by nonfederal grants. These are identified.



7.1 Personnel

None people and a faculty opening are described in this section. All nine are not full time. In fact, some give an extremely low percentage of their time and need explanation. The time percentages are:

Nicholas Negroponte	30%
Gordon Pask	30
Richard Bolt	10
Robert Solomon	10
Christopher Herot	90
Paul Pangaro	10
Guy Wienzapfel	0
Seth Steinberg	100
Bill Kelley	25
New Person	0

The explanation for this seemingly curious time allocation is simply that the forthright budgeting of our work reflects how we actually do it. Namely, there is a concurrency of projects in the lab and people informally brainstorm, review each other's work, and provide refreshed ideas. The mix may be our strength.

The mix of percentages outlined above reflects this reality. The 0 to ten percent types are budgeted in the sense of an internal "advisory board" that would meet at least weekly. The 25 to 30 percent types are the senior staff, for which there is a major research obligation.

The two full-timers are Seth Steinberg, recently appointed to the MIT Research Staff and Christopher Herot, a Research Associate in the Department of Architecture. Many of the day-to-day tasks of orchestrating this research would be in their hands. They both enjoy extensive, hands-on experience with interactive computing and computer graphics. Chris Herot has authored three successful papers on the topic and holds a growing representation in the computer graphics community.

7.1.1 Nicholas Negroponte

Curriculum Vitae:

Name: Nicholas Negroponte
Born: December 1, 1943

Education: MIT, Bachelor of Architecture
MIT, Master of Architecture

Professional Experience:
IBM, Cambridge Scientific Center, Cambridge, Mass., 1966-1969
Leo A. Daley Co., Washington, D.C. 1968-1971
Computation Corp., Bedford, Mass., 1968-
North Holland Publishing Company, Amsterdam, New York, Editorial Board, 1974.

Teaching Experience
MIT, Department of Architecture, Instructor, 1966-
MIT, Department of Architecture, Assistant Professor, 1968-1972
MIT, Department of Architecture, Associate Professor, (untenured), 1972-1975
MIT, Department of Architecture, Associate Professor, (tenured), 1975-
Yale, Department of Architecture, Visiting Professor, Spring, 1970
Berkeley, Department of Environmental Design, Visiting Professor, Winter, 1973
University of Michigan, Department of Architecture, Visiting Professor, Winter, 1975

Publications and Papers

Books:

Negroponte, N.
The architecture machine, Cambridge, Mass., MIT Press, 1970 (translated into Italian, Japanese, French, Spanish).

Negroponte, N.
Soft architecture machines, Cambridge, Mass., MIT Press, 1975.

Negroponte, N.
Anthology, computer aids to design and architecture, (edited), New York, New York, Mason and Lipscomb, 1975.

Chapters in Books:

Negroponte, N.
The return of the sunday painter or the computer in the visual arts, Future Impact of Computers and Information Processing, Michael Dertouzos and Joel Moses, editors, 1977.

Negroponte, N.
Introduction, pour l'architecture scientific, Yona Friedman, Cambridge, Mass., MIT Press translation, 1975.

Negroponte, N.
Limits to the embodiment of basic design theory, Basic Design Theory, William Spillers (editor), New York, New York, American Elsevier Publishing Co., Inc., 1974.

Negroponte, N.
Recent advances in sketch recognition (reprint), 1974 Best Computer Papers, Issac L. Auerbach, editor, New York, Petrocelli Books, 1974.

Negroponte, N.
Concerning responsive architecture, The Responsive House, Edward Allen (editor), Cambridge, Mass., MIT Press, 1974.

Negroponte, N.
Aspects of living in an architecture Machine, Design Participation, Nigel Cross (editor), London, Academy Editions, 1972.

Negroponte, N.
URBAN5 - A machine that discusses urban design, Emerging Methods

in Design and Planning, Gary T. Moore (editor), Cambridge, Mass., MIT Press, 1970.

Negroponte, N.
URBAN5: an experimental urban design partner, Computer Graphics on Architecture and Design, Murray Milne (editor), New Haven, Connecticut, Yale School of Architecture Publication, 1968.

Papers in Refereed Journals and Proceedings:

Negroponte, N., Pangaro, P.A.
Experiments in computer animation, submitted to SIGGRAPH Conference, 1976.

Negroponte, N.
Idiosyncratic systems approach to computer graphics, submitted to ACM, 1976.

Negroponte N.
Recent advances in sketch recognition, Proceedings of the National Computer Conference, New York, New York, June, 1973.

Negroponte, N.
HUNCH--an experiment in sketch recognition, Berlin, Gesellschaft fur Informatik, October, 1971.

Negroponte, N.
The architecture machine--a mini in teaching and research, Institute for Electrical and Electronics Engineers Digest, March 1971.

Other Publications:

Negroponte, N.
On being creative with computer-aided design, invited paper, IFIPS Conference, forthcoming.

Negroponte, N.
Idiosyncratic systems, Technology Review, forthcoming.

Negroponte, N.
Report on the architecture machine, 1975, Computer Aided Design, July, 1975.

Negroponte, N.
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Negroponte, N.
Mijloace electronice in proiectanea de arhitectura si urbanism, translated by Mircea Enache, Romania, Arhitectura, 20, 3-4, 127-131, 1972.

Negroponte, N.
HUNCH--An experiment in sketch recognition, Environmental Design: Research and Practice, Proceedings of the EDRA 3/ar 8 Conference, Los Angeles, January 1972.

Negroponte, N.
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Negroponte, N.
The architecture machine, Architecture and Urbanism, January-August, 1971.

Negroponte, N.
The semantics of architecture machines, Techniques and Architecture, May, 1971.

Negroponte, N.
Architecture machine, Architectural Design, 39, 510, September, 1969.

Negroponte, N.
Toward a humanism through machines, Architectural Design, 39, 511-512, Reprinted from Technology Review, 71, No. 6, 2-11, April, 1969.

Negroponte, N.
Towards a humanism through machines, Technology Review, 71, No. 6, 2-11 April, 1969.

Negroponte, N.
Humanism through machines, The Canadian Architect, 14, No.4, 29-34, April, 1969.

Negroponte, N.
Toward a theory of architecture machines, American Institute of Architects Journal, 51, No. 3, 71-74, March, 1969.

Negroponte, N., Groisser L.B.
Semantica delle macchine per l'architettura, Parametro, 10, 44--50, 1972.

Negroponte, N., Groisser, L.B.
URBAN5: a machine that discusses urban design, Emerging Methods in Environmental Design and Planning, Gary T. Moore (editor), Cambridge, Mass., MIT Press, 1970.

Negroponte, N., Groisser, L.B.
Environmental humanism through robots, Proceedings of the First Annual Environmental Design Research Association Conference, H. Sanoff and S. Cohn (editors), Raleigh, Design Research Laboratory, North Carolina State University, 1969.

Negroponte, N., Groisser, L.B.
Machine vision of models of the physical environment, Cambridge, Mass, MIT, Department of Architecture, Proposal to the National Science Foundation, 1969.

Negroponte, N., Groisser, L.B.
URBAN5, Ekistics, 24, No. 142, 289-291, September, 1967.

Negroponte, N., Groisser, L.B.
URBAN5: an on-line urban design partner, IBM Report, 320-2012, Cambridge, Mass., June 1967.

7.1.2 Gordon Pask

Curriculum Vitae

Name: Gordon Pask
Born: June 28, 1928

Education: Bangor and Liverpool Technical Colleges, diploma courses in Geology and Chemistry
Cambridge University, MA Natural Science Tripos, 1954
London University, Ph.D. in Psychology, 1963
Open University, DSc, 1975

Professional Experience:
System Research Ltd., Research Director, Co-founder, 1953
University of Illinois, researcher, adaptive teaching systems, chemical "liquid state" computing systems
Solartron, Solartron-Rheem, researcher in learning and teaching systems, 1955-1961
Aerospace Medical Research Laboratories, AFSC, Aerospace Researcher, 1960-1965
Burroughs Research Corporation, Researcher, 1960-1961
Office of Information Services, Air Force Office of Scientific Research, OAR, Aerospace Researcher, 1961-1966
US Army European Research Office, Researcher, 1963-1965
H M Home Office, Researcher in Cybernetics, 1964-1971
Aerospace Medical Research Laboratories (European Office for Aerospace), Researcher, 1966-1967
Office of Information Services, Air Force Office of Scientific Research, OAR (European Office for Aerospace Research), Researcher in Cybernetics
Ministry of Defense, Researcher, 1966-1970
Air Force Office of Scientific Research (European Office for Aerospace Research, Researcher, 1968-1969
SSRC HR 983/1, Researcher in Learning Strategies and Individual Competence, 1969-1970
Department of Employment, Researcher on Project titled Organisation and instruction of office skills involving communication, data retrieval and data recognition, 1969-1971

NTGB, Researcher on Project titled, Domestic consumer response prediction, 1970-1971
SSRC HR 1203/1, Researcher on Project titled, Uncertainty regulation in learning applied to procedures for teaching concepts of probabilty, 1970-1971
R R L, Researcher on Project titled, Driving strategies for learner drivers, 1970-1973
SSRC HR 1434/1, Researcher on Project titled, Educational methods using information about individual styles and strategies of learning, 1971-1973
USAF, Researcher on Project titled, Cooperative computing systems for echo detection with respect to moving targets, 1972
SSRC HR 1876/1, Researcher on Project titled, Entailment and task structures for educational subject matters, 1972-1973
USAF, Researcher on Project titled, strategies disposition tests and the influence of learning strategy on the performance and breakdown of skills, 1972-1973
SSRC HR 2371/1, Researcher on Project titled, Applications and developments of a theory of learning and teaching, 1973
SSRC HR 2708/2, Researcher on Project titled, Learning styles, educational strategies and representations of knowledge: methods and applications, 1974-1979
US Army, Researcher on Project titled, Current scientific approaches to decision making in complex systems, 1975
USAF, Researcher on Project titled, The influence of learning strategy and performance strategy upon engineering design, 1975
US Army, participant in second conference on current scientific approaches to decision making, 1976
US Army, Researcher on Project titled, Cognitive mechanisms and behaviours in learning involving decision, 1976
Mathematical Biosciences, Editorial Board
Journal of Man Machine Studies, Editorial Board
ICA Advisory Board
AGARD, NATO, ILO, Consultant, Committee Member

Teaching Experience:
University of Illinois, Urbana, Ill., Electrical Engineering Research Laboratory, Assistant Professor, 1959
University of Mexico, University of Illinois, University of Oregon, Georgia Institute of Technology, University of Illinois, Chicago Circle, Visiting Professor
Brunel University, Institute of Cybernetics, Professor, present position
Open University, Institute of Educational Technology, present position

7.1.3 Richard Bolt

Curriculum Vitae:

Name: Richard A. Bolt
Born: February 24, 1934

Education: University of Massachusetts, B.A. in English Literature, 1957
Brandeis University, M.A. in Psychology, 1969
Brandeis University, Ph.D. in Psychology, 1975

Professional Experience:
American Mutual Liability Insurance Company, Wakefield, Mass., Underwriting; Programming and Systems Analysis, 1958-1962
Bolt Beranek and Newman, Inc., Cambridge, Mass., Programming and Systems Analysis, 1962-1966
MEDINET Department of General Electric Company, Watertown, Mass., Medical Systems Analysis, 1966-1967
The Cambridge Project, MIT, Cambridge, Mass., Editorial Technical Writing, 1972-1974
Architecture Machine Group, Dept. of Architecture, MIT, Cambridge, Mass., Consultant, Research Associate, 1976-

Publications and Papers:

Boilen, S., Baruch, J.J., Hughes, J.H., and Bolt, R.A.
An interpretive communications system in the hospital environment. Paper delivered by R.A.B. at 1964 annual meeting of Digital Equipment Users Society, Dayton, Ohio, September 1964. Published in DECUS Proceedings, 1964.

Bolt, R.A., Allen, S.I., and Webb, H.W.
An on-line retrieval system. Paper delivered by R.A.B. at chemical literature symposium, 149th National Meeting, American Chemical Society, Detroit, Michigan, April 1965. Published in Journal of Chemical Documentation, 1966 (Feb.), 6, (1), 57-60, under title "Some Information Indexing Techniques in a Real-Time Hospital Computer System."

Bolt, R.A.
Effects of ensemble size and logical condition in high-speed memory search. Unpublished Master's Thesis, Brandeis University, 1969.

Bolt, R.A.
High-speed scanning in human memory: Effects of processing capacity, item category, and memory locus. Unpublished Doctoral Dissertation, Brandeis Universtiy, 1975.

Wingfield, A., and Bolt, R.A.
Effects of ensemble size and number of targets in scanning of immediate memory. Paper delivered by R.A.B. at meeting on Short-Term Memory at the 41st Annual Meeting of the Eastern Psychological Association, Atlantic City, New Jersey, April 1970.

Wingfield, A., and Bolt, R.A.
Memory search for multiple targets. Journal of Experimental Psychology, 1970, 85, 45-50.

7.1.4 Robert Solomon

Curriculum Vitae:

Name:	Robert D. Solomon
Born:	August 9, 1945
Education:	Polytechnic Institute of Brooklyn, B.S.E.E., 1967 MIT, Master's Degree (S.M.E.E.), 1969 MIT, Electrical Engineering Degree, 1970 MIT, Ph.D. in Electrical Engineering, 1975

Professional Experience:

Bell Telephone Laboratories, Holmdel, New Jersey, Designer, 1966
MIT, Cambridge, Mass., Designer, 1970-1974
General Radio Company, Concord, Mass., research and development, 1969-1974
Solotest Corporation, Cambridge, Mass., President and Director of Engineering, 1972-

Teaching Experience:

Worcester Polytechnic Institute, Assistant Professor of Electrical Engineering, 1975-

Publications and Papers:

Solomon, R.D.
A discrete commanding system for increasing the dynamic range of delta modulation, Bell Telephone Laboratories, Holmdel, New Jersey, September, 1966.

Solomon,R.D.
A DECOR system for detecting and correcting spike noise in an FSK communications system, Polytechnic Institute of Brooklyn, Memo for Quarterly Report on NASA Contract for Threshhold Extension, June, 1967.

Solomon, R.D.
A study of the limitations on the packing density of integrated circuits, MIT Master's Thesis, 1968.

Solomon, R.D.
Pre-emphasis noise reduction in a video tape recorder system, MIT Report, 1969.

Solomon, R.D.
A study of flat face image systems, MIT Report, 1969.

Solomon, R.D.
Beat frequency oscillator mixer theory, General Radio Memo, 1969.

Solomon, R.D.
Phase and frequency locked loop system theory, General Radio Memo, 1969.

Solomon, R.D.
New real-time spectrum analyzer, presented at the 79th Meeting of the Acoustical Society of America, Atlantic City, New Jersey, 1970.

Solomon, R.D.
Artificial biofeedback systems in humans, General Radio Memo, 1969.

Solomon, R.D.
A bidirectional binary to BCD converter, EDN, 1972.

Solomon, R.D.
Design of a low cost solid state color head, presented at the SPSE Conference, Boston, Mass., 1974.

Solomon, R.D.
Color coding for a facsimile system, MIT Ph.D. Thesis, 1975.

Solomon, R.D.
A color facsimile system which can be economically implemented with a microprocessor, presented at the International Conference on Advanced Signal Processing Technology, Lausanne, Switzerland, 1975, published in conference proceedings.

Solomon, R.D.
The luminance scaled chromaticity transform, presented at the Optical Society of America Annual Meeting, October 21, 1975, Boston, Mass. Published in JOSA, October, 1975.

Solomon, R.D.
Real time color picture coding, presented at the Picture Coding Symposium, Asilomar, Ca., January, 1976.

Solomon, R.D.
Efficient frame memory storage of a color TV picture, presented at the Society for Information Display 1976 International Symposium, Beverly Hills, Ca., 1976.

Solomon, R.D.
Color picture coding for facsimile, MIT RLE Progress Report No. 117, pp 305-310, January, 1976.

7.1.5 Christopher Herot

Curriculum Vitae:

Name: Christopher Frederick Herot
Born: December 30, 1950

Education: MIT, B.S. in Art and Design (Film and Photography) 1972
MIT, M.S. in Computer Science (Department of Electrical Engineering), 1974

Professional Experience:
MIT, Department of Civil Engineering
Materials Research Laboratory
Programmer 1969-1971
MIT, Department of Architecture, Architecture Machine Group, Programmer 1971-1972, Graduate Research Assistant 1972-1974, DSR Research Staff 1974-1976

Publications and Papers:

Herot, C.F.,
Using context in sketch recognition. Master of Science thesis, MIT, 1974.

Herot, C.F., Negroponte, N., and Markowitz, J.
Idiosyncratic systems. Architecture Machine Group, MIT, 1975.

Herot, C.F.
Current events in graphical input techniques. for SIGGRAPH 1976.

Herot, C.F.
Sketch recognition for computer aided design. for ACM/SIGGRAPH Workshop on user-oriented design of interactive graphics system. Pittsburgh, Pennsylvania, October, 1976.

7.1.6

Curriculum Vitae:

Name: Paul Pangaro
Born: December 14, 1951

Education: MIT, B.S. in Humanities and Electrical Engineering, 1974

Professional Experience:
MIT Project MAC, Cambridge, Mass., Dynamic Modelling Group, Designer, 1970
Education Development Center, Newton, Mass., Consultant to Topology Films Project, 1971-
Education Development Center, Newton, Mass., Participation in writing, designing, filming, narration of computer-generated film
MIT Council for the Arts, Cambridge, Mass., Commision of Written Report to Evaluate MIT's Needs for Future Arts Programs and Facilities
MIT Education Research Center, Cambridge, Mass., Manager for Computer-Generated Film Facility, 1972-1973
MIT Research Laboratory of Electronics, Cambridge, Mass., Research Consultant, 1974-1975
MIT, Architecture Machine Group, Computer Animation, 1976-

Teaching Experience:
Seton Hall Preparatory School, South Orange, New Jersey, Tutor, 1968-1969
MIT, Unified Science Study Program, Education Research Center, Instructor in Computer Modelling, 1969-1972
Children's Mime Workshop, Boston, Mass., Instructor
MIT Dramashop, Instructor in Improvisation

Theatre Experience:
Actor with the Following Companies
MIT Dramashop
Harvard Summer School Summer Repertory
Boston Summerthing

Pocket Mime Theatre, Boston
Tempo Theatre Company, Boston

Roles:

Green Eyes	Deathwatch	Genet
Angelo	Measure for Measure	Shakespeare
Hamm	Endgame	Beckett
John Worthing	The Importance of Being Earnest	Wilde
Moon	The Real Inspector Hound	Stoppard
Gus	The Dumbwaiter	Pinter
Bluntschli	Arms and the Man	Shaw
Old Mahon	Playboy of the Western World	Synge
Iago	Othello	Shakespeare
Jerry	A Pound on Demand	O'Casey
Che Guevara	MacCrune's Guevara	Spurling
Window Washer	Witness	McNally
Frankie	Birdbath	Melfi
Aristophanes	The Clouds	Aristophanes
Soldier	L'Histoire du Soldat	Stravinsky
First Voice	Under Milk Wood	Thomas
Henry Drummond	Inherit the Wind	Lawrence & Lee
Chorus Leader	Oedipus Rex	Sophocles
Captain Andy	Showboat	Kern & Hammerstein
Wayne Frober	Colonial Dudes	Duberman
Sam	Moon	Heide
Etienne	The Labryinth	Arrabal
First Musician	The Cat and the Moon	Yeats
Paul	Merlin Finch	Dizenzo
The Friend	The Wedding	Brecht
Mr. Witherspoon	Arsenic and Old Lace	Lindsay & Crouse
Blick	The Time of Your Life	Saroyan
Owen	Jenny Kissed Me	Kerr

Directing Experience:

Under Milk Wood by Thomas
Out At Sea by Mrozek
Escurial by deGhelderode
Birdbath by Melfi

Muzeeka by Guare
The Physicists by Durrenmaff

Professional Training:

Pocket Mime Theatre, Boston
Private student for four years of Joan Tolentino, Actress and Teacher
Student for two years of singing coach Margot Warner

Awards:

Finalist, University Resident Theatre Association, 1973
MIT Stewart Award, for contributions to the Drama program, in acting, directing, teaching, and producing in the Director of Drama's absence

Technical Work:

Assistant Stage Manager, Theatre Company of Boston
Publicity Director, MIT Dramashop
Stage Manager, MIT Dramashop
Crew, Loeb Drama Center, Cambridge, Mass.

Computer-Generated Film:

Narrated, co-designed, filmed two topology education films, "Regular Homotopies in the Plane, Parts One and Two," Sponsored by the Education Development Center, Newton, Mass. Part One awarded the CINE Golden Eagle, Bronze medal in the Congress of International Science Film Association, Hungary, September, 1974. Part Two awarded the CINE Golden Eagle, October, 1974

Design and filming of neurophysiology film on threshold oscillations and intermittant conduction in nerve fiber, Research Laboratory of Electronics, MIT, screened at Society for Neuroscience Conference, Toronto, 1976

Stereo-scopic films of a hypercube in four dimensions, Computer-Generated Film Facility, MIT

Publications and Papers:

Negroponte, N., Pangaro, P.A.
Experiments with Computer Animation, submitted to SIGGRAPH Conference, 1976.

7.1.7 Guy Weinzapfel

Curriculum Vitae:

Name:	Guy Weinzapfel
Born	June 24, 1942

Education: University of Arizona, Bachelor of Architecture, 1965
MIT, Master of Architecture, 1971

Professional Experience:
Cook and Swaim, Architects, Tucson, Arizona, Draftsman/Designer, 1965-1966
Campbell Aldrich and Nulty, Architects, Boston, Mass., Designer, 1966-1967
The Architects Collaborative, Cambridge, Mass., Architect, 1967-1968
JOBS 70 Training Program (US Department of Labor), Boston Architectural Center, Program Director and Instructor, 1970-1972
Private Practice, Architect, Lexington, Mass., 1971-
MIT, Cambridge, Mass., Computer Applications in Architecture, Research Associate, 1971-
US Army Corps of Engineers, Champaign, Ill., Consultant, 1972-
US Army Corps of Engineers, Champaign, Ill., Responsible for Preparation of Research Proposals, Supervision of Research Staff, 1972-
Department of Environment, Centre for Mathematics Methodology and Information, France, Consultant, Staff Trainer

Teaching Experience:
MIT, Department of Architecture, Graduate Research Assistant, 1968-1970
Boston Architectural Center, Lecturer, 1972
MIT, Department of Architecture, Consultant in Design Methods

Publications and Papers:

Weinzapfel, G.
Space arrangement, Architectural Design, September, 1969.

Weinzapfel, G.
EDRA II, Carnegie-Mellon Institute, Pittsburgh, 1970.

Weinzapfel, G.
IMAGE - a computer design aid system, Proceedings of the share/ACM/ IEEE design automation workshop, Atlantic City, June, 1971.

Weinzapfel, G.
Computer aided space synthesis, Industrialization Forum, October 1971.

Weinzapfel, G.
The IMAGE system - its role in design, Proceedings of the International Conference on Computers in Architecture, York, England, 1972.

Weinzapfel, G.
It might work, but will it help, Proceedings of the Design Activity International Conference, London, 1973.

Weinzapfel, G.
IMAGE: computer assistant for preliminary architectural design, Spatial Synthesis in Computer Aided Building Design, Charles Eastman, editor, Essex England, Applied Science Publishers, 1974.

Weinzapfel, G.
Following the yellow brick road, Computer Aids to Design and Architecture, Nicholas Negroponte, editor, New York, Mason/ Charter Publishers, 1975.

Weinzapfel, G.
The Falco project: a case study of owner/designers, Architecture Machine Group, Department of Architecture, MIT, Cambridge, February, 1976.

Weinzapfel, G.
Architecture by yourself: an experiment with computer graphics for house design, Proceedings of ACM/SIGGRAPH Conference, Philadelphia, July, 1976.

Weinzapfel, G.
Interactive graphic techniques in architectural design, Presentation at IEEE Workshop on Human Engineering Aspects in Automated Design, Lansing, Mi., October, 1976.

Weinzapfel, G.
Interactive techniques for multi-level space allocation, Presentation at Institute for Research In Information and Automation, (IRIA), Paris, France, June, 1976.

7.1.8 Seth Steinberg

Curriculum Vitae:

Name:	Seth Alan Steinberg
Born:	July 8, 1954
Education:	MIT, B.S. in Electrical Engineering, 1974 MIT, M.S. in Electrical Engineering and Computer Science, 1976
Professional Experience:	Meta-Language Products, Developed a business oriented natural language data base system, New York City, New York, 1971 Department of Social Services, New York City, New York, Informational Flow Director, 1972 Architecture Machine Group, MIT, Cambridge Mass., research assistant, 1973-1976

Publications and Papers:

Steinberg, S.A.
The interdata PL/I manual, to be published the summer of 1976.

7.1.9 Bill Kelley

Curriculum Vitae:

Name:	William F. Kelley
Born:	March 2, 1932
Education:	Rindge Technical High School, Electrical Course, 1951 Lincoln Institute of Northeastern University, Associate degree in Electronic Engineering Northeastern University, School of Business, BBA in Engineering and Management, 1959 Northeastern University, Lincoln College, certificate in Control Systems Engineering, 1963 Fitchberg State College, State Certification as Occupational Teacher in Electronics, 1974
Professional Experience:	Lincoln Laboratory, Lincoln, Mass., technician, Engineering Assistant, 1954-1967 MIT, Cambridge, Mass., Staff Engineer, Lecturer, Research Laboratory of Electronics, Communication Biophysics Group, 1967-1973 MIT Lincoln Laboratory, Engineering Assistant (Air Traffic Control), 1973-1976

7.1.10 New Faculty Position

A reprint of one of the advertisements associated with our search to fill a new faculty opening in Computer-Aided Design (CAD) follows. We include this in the proposal material to relieve the reader of what would otherwise appear to be a serious bottleneck in our faculty.

We expect additional openings, possibly even a chair, to become available as the Arts Program gathers momentum. Such new positions would be for what we are calling the "interstices" of video-computers, computer-graphics, film-environmental art, and the like.

It is also important to add that the departments of Naval Architecture, Civil Engineering, and Mechanical Engineering also offer Computer-Aided Design courses in a facility which they jointly own and operate. (That facility happens to be similar to ours in many of the brand-name devices - Interdata, Imlac - hence, we do share software.) This is mentioned with the new faculty position because joint teaching programs will surely emerge. Discussions are in progress.

Massachusetts Institute of Technology

Faculty Position in Computer Aided Design

A new faculty position in Computer Aided Design has been created within The Department of Architecture. Candidates for this opening are invited to submit their resumes and any additional information by December 31, 1976 to:

Professor John Habraken, Head
Department of Architecture
Massachusetts Institute of Technology
77 Massachusetts Ave.
Cambridge, Massachusetts 02139

The position includes 50% research and 50% teaching. The latter entails:

1) An introductory design methods subject at the graduate level, but available to undergraduates.
2) A graduate seminar centered on the candidate's expertise
3) Ph.D. and M.S. Thesis supervision.

Prerequisites include:

1) Ph.D. equivalent in Computer Science
2) Professional degree or experience in design:
   a) art
   b) architecture
   c) graphics or
   d) planning
3) Experience teaching at the college level
4) Demonstrated ability and interest in research.

The position can be at either the Assistant or Associate Professor level; salary to be negotiated.

7.2 Educational Setting

The teaching that relates to our current work suffers from the bottleneck in our faculty. The previous section absorbs some of this problem. Concurrent with this proposal, Dr. Gordon Pask is being nominated for consideration as Adjunct Professor. This will further help rebalance our teaching and research.

None of the follwoing subsections address the relation to professional architecture programs, in part because they will play a lesser role given a deflated emphasis on applications, and in part because their influence is usually measured in the intangibles of spirit, attitude and curiosity. Architecture students are tactile people. They are educated to ask questions about questions as frequently as, or even more than, answering questions!

Furthermore, within the Architecture Department, we find MIT's visual arts programs: film/video, environmental art, the Visible Language Workshop, and photography. Currently, the visual arts account for 50 percent of our users outside formal course work. This, too, is an underlying influence upon our style of research.

7.2.1 Companion Subjects

Three subjects are directly related to interactive graphics: Architecture's Introduction to Information Processing, Geometry and Computation, and Machine Intelligence in Design. The first two are scheduled to be concatenated into a simple subject: Computer Graphics and Animation. And a new subject in Design Methods is being planned, broader than the current CAD offerings.

These subjects account for 40 to 60 students per semester, ranging from freshmen to postdoctoral participants. This population is handled on-line, hands-on using some of the most temperamental but current hardware and software developments sprouting from our research. Our current method of operations is to turn over two computer systems to these subjects, six hours a day. (The lab itself is a twenty-four hour a day, seven days a week operation.

The following descriptions are taken from the MIT course catalogue.

4.20 Introduction to Information Processing (A)

Prereq.: Permission of Instructor
Year: G (1)
3-3-3

Basic principles of computer hardware organization, programming systems, languages and problem solving with digital computers. Laboratory experience in computer programming, computer operation, and the application of computers to problems of architectural interest. Different human-machine communication modes exemplified with exercises and demonstrations in computer graphics, information-retrieval systems, and time-sharing.
N. P. Negroponte

4.201 Geometry and Computation in Architecture

Prereq.: ——
Year: U (1)
4-0-4

Introduction to projective geometry, orthographic and perspective, represented both graphically and mathematically. Techniques exercised with computer graphics facilities. Students unfamiliar with computer programming will be introduced to FORTRAN; others will have the opportunity to employ less conventional computer languages.
N. P. Negroponte

4.24 Computer-Aided Urban Design (A)

Prereq.: Permission of Instructor
Year: G (1)
3-0-6

Workshop with students pursuing research projects of their choosing within the context of architect-machine communication as an aid to the design of urban environments. Special emphasis on machine-partnership and programs of evolution. (Programming experience necessary. Master's candidates may take 1.00 or 4.20 or 6.030 simultaneously.)
N. P. Negroponte

4.25 Machine Intelligence in Design (A)

Prereq.: Permission of the Instructor
Year: G (2)
3-0-6

Experimentation with machines that learn about their users, in particular, their users' needs, desires and attitudes. Application of machines which directly view physical environments; applying studies in pattern recognition, linguistics, and self-organizing systems. Student initiated research and visiting specialists. (Programming experience necessary.)
N. P. Negroponte

7.2.2 Ph.D. Concentration in Computer Graphics

The Architecture Department is in its second year of offering a Ph.D. level program. Seven students are currently in the program, for the most part concentrating within the framework of History, Theory, and Criticism. This new program's operation and its expansion beyond History, Theory, and Criticism is guided by a Ph.D. committee.

As a member of that committee, the Principal Investigator is actively engaged in expanding the Ph.D. to include Design Methods in general and Computer Graphics in particular. We will be entertaining one application in January 1977 for a Ph.D. concentration in Computer Graphics in concert with the aims of this proposal (if funded, this grant would use 1 of the 2.5 Research Assistants listed in the budget to fund this Ph.D. student).

We have purposely elected to pursue a Ph.D. track outside the Institute's Electrical Engineering Department in order to preserve the anomalous but engaging environs of more traditional graphics media: film, video, offset, photography, xerography, etc. However, the reader should be aware that MIT does allow for joint Ph.D. programs. Last year we had two applications for such work: Architecture Machine -- Artificial Intelligence Laboratory.

7.2.3 M.S. Program in Computer-Aided Design

The following three pages are photostatic reductions of our current M.S. brochure describing the newly created M.S. Program. It is not the "junior" degree of the previously discussed Ph.D. It is a separate program, intimately related to a growing Arts Program (discussed in subsection 7.2.5).

The M.S. Program officially started this fall. We presently have five students enrolled in the Computer-Aided Design option, working within our current NSF grant. The range of activity is witnessed by the diversity of planned thesis topics: computer animation, frame buffers, spatial data management, design overlaying, distributed graphics.

The origins of this particular program and educational setting are illustrative of the shifts in our patterns of research. Namely, the M.S. grew out of increasing momentum within satellite subject areas which were first initiated to serve the needs of architectural students pursuing professional curricula. Over time, these service subjects, in some cases, assumed enough critical mass to offer graduate research and study in a particular discipline (in this case: film/video, computers, environmental art). The M.S. is a formalization of this and an encouragement to pursue further professionalization in these areas. We are unaware of any other program like it in the United States; the Royal College of Art in London has a close approximation in their Design Methods Program (recently expanded from research into teaching).

master of science

The Program

The Master of Science (M.S.) Program is new. It was initiated in 1976 in response to a long history of diversity in areas of study offered by the Department of Architecture. Previously, part-time, non-degree studies in technology or the visual arts have offered the Institute a repertoire of general studies, the Department a sequence of distributed requirements, and the occasional student a program of concentration. The M.S. is formalization of the latter, with the three-fold purpose of: offering students professional opportunities in areas of scientific inquiry and visual study outside the architectural professional track; contributing to undergraduate and architectural programs by having a more critical mass of teaching and research; stimulating advanced research programs by attracting graduate students committed to a specific line of inquiry. The M.S. is an experimental program without the precedents of specific subject sequences, or career opportunities. As such, prospective applicants are urged to make personal contact with the specific programs.

Currently, three programs are offered within the M.S. They are: film/video, visual studies, and computer-aided design. Their selection results from an existing momentum in teaching and/or research, formidable enough to justify concentrated study. Each group has a very specific bent on their topic. Film/video has a long-standing reputation in *cinéma verité* or *direct film*, punctuated by research and development in sync sound super-8. Visual studies is marked by a tradition of combining art and technology launched by the early work of Gyorgy Kepes. Computer-aided design is flavored by the quest for interactive and intelligent systems.

Degree requirements are common in all three programs. They have been fashioned in a manner to encourage students to capitalize upon other areas in the Department and the Institute at large. In contrast to apprenticing with a mentor, candidates are expected to outline their own area of interest. Our educational goals are tinted by a self-interest in nurturing fields of study available uniquely at MIT. Consequently, prospective applicants should see their own educational objectives as research-based and professionally oriented toward acquiring skills and insights, while at the same time participating in the building of a graduate program.

The faculty are well-known innovators in their fields. However the academic staff is not limited to the advisors in charge of each program, but stretches across the whole Department, including Research Associates directing very specific research projects. The M.S. program sees itself as a collage of colleagues, rather than a classroom of exercises.

The Department of Architecture offers three graduate programs of study: The Master of Architecture (M.Arch.), the Master of Architecture in Advanced Study (M.Arch.A.S.) and the Master of Science (M.S.). The Department also offers a four year undergraduate program that leads to the degree of Bachelor of Science in Art and Design (B.S.A.D.).

The M.Arch. is the first professional degree for students interested in the professional practice of architecture. The M.Arch.A.S. is the second professional degree which affords advanced study in: Buildings as Systems—Design Constants, Urban Settlement Design in Developing Countries, Environmental Design, and Special Interest Areas (including: Environmental Arts, Design Technology, Energy Systems, and History/Theory/Criticism of Art and Architecture, Housing and Related Design Methods). The M.Arch.A.S. intersects noticeably with the M.S. program. Therefore, students with a previous B.Arch. or M.Arch. should review that brochure as well. A technical difference which should be noted is that the M.Arch.A.S. has a residency requirement (2 years), while the M.S. is credit-bound (100 units).

The Master of Science degree is awarded upon satisfactory completion of an approved program of study. This includes a minimum of 100 units plus a thesis acceptable to the Department. Any 42 of the 100 should be in "A" subjects. ("A" subjects are those intended primarily for graduate students and are so indicated in the Description of Subjects given in the General Bulletin.)

Thirty-two (32) credit units per term may be considered a full-time load. However, a student without a teaching or research assistantship can normally average between 45 and 50 units per term at the Institute. This means that a student with an assistantship should expect the program to take a minimum of four semesters. An incoming student without an assistantship should anticipate a duration of three semesters, devoting most of the third semester to thesis. Students who have received their Bachelor of Science degree at MIT may be able to transfer any applicable units (beyond the 360 needed for the Bachelor of Science) to the Master of Science degree. Such students may thereby be able to complete the remaining Master of Science program requirements in two semesters of full-time study.

Film/Video

The M.S. degree program formalizes a practice evolved at the Film Section over the past several years. Taking people who have exhibited some competency in film and intensively training them in the techniques of unscripted sync sound filmmaking (*cinéma verité*), we have achieved remarkable results in relatively short periods of time. The program emphasizes deepening and refining of filmmaking skills, as opposed to more narrowly defined craft skills. Camerawork, editing, sound and film concepts are treated as parts of a whole rather than as particular skills that result in the professions of editor, cameraperson, director, etc.

Filming is in both 8mm and 16mm. Through the pioneering efforts of Richard Leacock at MIT, a sophisticated Super-8 sync sound system was developed, making that gauge a serious medium for filmmaking. The degree program is small, being comprised of about seven students. This allows good access to sophisticated shooting and editing equipment in either gauge. M.S. candidates are expected to both finance and complete several short sync sound films and at least one more extensive film which will be considered the thesis film.

Beside's work in the more traditional 1960's notion of *cinema verite* or direct cinema, staff and students have made films and experimented with mixed media (opera, video theatre), autobiographical, filming public spaces, etc. As television provides a major distribution outlet for film, the Film Section looks forward to examining the potentials for creative programming, combining film, video, and live television.

Three full-time filmmakers, one part-time video artist, supplemented by visiting filmmakers and video artists, constitute the instructional staff. An atmosphere of intensive filmmaking, experimentation, and extensive film viewing, combined with adequate access to equipment and a staff composed of serious filmmakers make the Film Section a unique place to learn filmmaking.

Visual Studies/ Environmental Art

The Visual Studies Environmental Art section of the M.S. graduate program results from the willingness of the artists at the Center for Advanced Visual Studies to share their experiences with students working towards related objectives. Among the primary fields of specific interest to CAVS are: environmental sculpture and painting and sculptural architecture of all scales; public leisure installations; celebrations; elemental, kinetic art and aesthetic psychological ecology.

Further disciplines of art and art research pursued by Fellows of CAVS have become, consequently, and with increasing emphasis, developmental media work—especially progressive video art—and new forms of kinetic art, such as holography, laser research and multi-modal performance.

The founding philosophy of the Center's efforts is based upon the elementary human need of expression in all available media—hence, the Center's place at MIT and its continuing commitment to communicating and integrating efforts in art and technology. Twenty resident and visiting artist Fellows work at the Center on personal and communal projects which enhance the collaboration of artists, scientists, scholars and engineers. At the same time the artists contribute to CAVS' teaching program under the direction of Otto Piene, head of CAVS since 1974, and Professor Robert Preusser, CAVS' director of education. The Center was founded in 1967 by Gyorgy Kepes and it has maintained since its unique character as a place for the synthesis of artistic, scientific and technological contributions to contemporary social and cultural needs.

Among past Fellows of CAVS were Maryanne Amacher, Douglas Davis, Juan Downey, Rockne Krebs, Vassilakis Takis, Harold Tovish, Wen-Ying Tsai, Stan VanDerBeek. Present Fellows include: Peter Campus, Harriet Casdin-Silver, Paul Earls, Ron Hays, Carl Nesjar, Jon Rubin, Alan Sonfist, Friedrich St. Florian.

Because of its specific character which demands intricate attention the number of students in the Visual Studies Environmental Art graduate program is currently limited to four. This permits the development of interdisciplinary programs for each student according to his or her individual need and vision. The layout of artistic, scientific and technological studies follows the students' projected objectives, and a balance between studio work and intellectual studies will be established. Students of the program will have studio spaces in the CAVS building so that they will partake in the Center's activities and at the same time be in constant personal touch with the resident artists. Besides vivid cooperation with the MIT faculty at large strong ties are at work between CAVS artists, students and faculty of the School of Architecture and Planning's Department of Architecture with which CAVS is associated

Computer-Aided Design

Opportunities in the Computer-Aided Design program are clearly driven by ongoing, sponsored research. Accordingly, prospective applicants are urged to write for copies of current research proposals and reports in order for us to portray our setting most accurately. The breadth of research activity crosses all dimensions, from basic to mission-oriented, from one discipline to another. The only unifying dimension is found in the application and development of "interactive and intelligent" systems.

The past decade of Computer-Aided Design has not yielded handsome results. Instead, it has been a self-serving exercise in fiddling with details, for the most part unrelated to what anybody would call "design". In part this results from a lack of richness in the media of interaction between user and machine, to the point of forcing such unnatural translations that outputs are, at best, gratuitous. And, in part, this is because of a lack in computer-based knowledge of the subject matter and, more importantly, of the person using it.

A major theme has been what we call *idiosyncratic systems*. These are personalized computer systems, that grow and change as a result of their use by a specific person. The process is viewed much like human-to-human acquaintance, developing: inference making systems, interpersonal hypotheses, and error correction mechanisms. This theme is currently seen in the following sponsored research: personalized design systems, architecture-by-yourself, computer-aides to technical writing, graphical input techniques.

Other areas of study include the development of multiple media Man-Machine interaction, understanding color perception, and managing complex descriptions. Applications include animation, graphic design and production, numerical control, space allocation, and housing design. Additionally, there are hardware developments and opportunities in raster scan displays, digital video, and flatscreen television.

The Computer-Aided Design program is loosely tied into the activities of the Laboratory for Computer Science. Yet, more informally, we find our students collaborating with the Artificial Intelligence Laboratory and the Division for Study and Research in Education. Prospective applicants should at least read the General Bulletin to understand some of the related activities of the above groups.

In our own laboratory, we provide the facilities to both use and develop the most current computer graphics. These include ten calligraphic CRT Displays, two raster scan systems, a turn-key computer-aided design and drafting system, and numerous input devices. These are driven by six mini-computers in a network enhanced by a large number of peripherals. Laboratory life is a hands-on phenomena, far more pronounced than time-sharing, clearly unrelated to batch processing experience.

A candidate is expected to have extensive computer programming experience. A background in some field of design is helpful, but not a prerequisite.

Research Assistantships are generally available. However, a continuing student is given preference in both allocation and timing of commitment. Candidates looking for financial assistance should be aware of the fact that research funds are awarded according to the government's fiscal year and hence announcement of these awards may be delayed.

Curricula

Curricula will depend very much upon the background and the selected concentration of the individual. Candidates should not feel bound by the three areas described in the M.S. program, but should also consider joint programs and combined areas of study. Examples of such studies can be found in video art, computer art, computer animation, and media research.

During the first semester students will be expected to examine all the resources which are available at MIT. Moreover, because of the personal nature of the program, students will not be permitted to establish the final sequence of subjects leading to the degree until the completion of one semester of study.

Any 40 of the required 100 units must be taken outside the field of concentration. While precision of what is and is not in the field of concentration proves impossible, candidates should recognize and expect to conform with the intention of the requirements. That is to say, students will be expected to take subjects, conduct laboratory experimentation, participate in seminars, or work in studios, outside both the area of their specific concentration and outside their group of co-workers.

Financial Assistance

The tuition for all regular full-time students will be $2000 per semester, $4000 for the academic year 1976-77.

At this time, scholarships are not available for this program. In general, financial assistance is limited to what the specific program and its research can offer. Students interested in financial aid should address their inquiries to the director of the specific programs:

Film Video
Richard Leacock
Room E21-010
or
Visual Studies
Otto Piene
Room W11
or
Computer-Aided Design
Nicholas Negroponte
Room 9-518
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

Admissions

Admissions to the Department for the M.S. program is by competition among candidates for the places available. These places are currently allocated to the program at large and not to the specific units of study.

The program requirements include a previous Bachelor's degree or equivalent in any subject and evidence of previous experience and achievement in the proposed field of study.

An interview is required of all applicants except in those cases where it would be a financial burden (for instance, for foreign students). Contact the director of the program to which you are applying.

The deadline for the receipt of all parts of the application for admission to the Department in September 1977 is January 15, 1977. The Department does not allow deferred enrollment.

A properly completed application consists of the following six items:

1
A completed Graduate Application for Admission form. (Foreign students must complete a Graduate Application for Admission from Foreign Citizens form.)

2
Official transcripts of the applicant's academic record to be sent to MIT by the Registrars of the colleges and universities attended.

3
Three letters of reference from teachers with whom the applicant has recently studied and/or from other professionals acquainted with the applicant's work.

4
A statement describing the applicant's personal interest, background and motivation for participating in the M.S. program.

5
A non-refundable application fee of $20. Payment should be made by check or money order, payable to the Bursar, MIT.

All of the above should be sent to:

Director of Admissions
Room 3-108
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

6 Portfolio
The requirements differ for each group:

All applicants to the **film/video** group must submit a film or video tape which they have made and which demonstrates their competency in the field.

Applicants to the **visual studies** group must submit a portfolio of their work which contains slides and/or photographs showing the nature and scope of the applicants' best creative work.

Applicants to the **computer-aided** design program must be able to demonstrate their competency in computer programming and should submit any articles or papers they have written which are relevant to their proposed work.

Applicants either must include return postage for their portfolios or arrange to pick them up. Portfolios remaining in the Department after September 15, 1977 will be destroyed.

Portfolios should be sent directly to:

Department of Architecture
Room 7-303
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

Note: The Graduate Record Exam is not required by the Department of Architecture.

(Foreign applicants should be prepared to submit documented proof of financial support. These documents will be required later by the Institute, after a candidate has been accepted by the Department, in order that an I-20 form may be issued and a visa obtained.)

It is the responsibility of the applicant to be sure that the completed application and supporting material are received by January 15, 1977. If all materials are not received by that date, the application may not be considered for admission and the Admissions Office will not return the application fee.

The Massachusetts Institute of Technology admits students of any race, color, sex, religion, national, and ethnic origin to all rights, privileges, programs, and activities generally accorded or made available to students at the Institute. It does not discriminate against individuals on the basis of race, color, sex, religion, national, and ethnic origin in administration of its educational policies, admissions policies, scholarship and loan programs, and athletic and other school administered programs, but may favor U.S. citizens or residents in admissions and financial aid.

The Institute has created and implemented and will continue to implement an affirmative action plan expressing its commitment to the principle of equal opportunity in education.

Further inquiries should be addressed to:

Department of Architecture
Room 7-303
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts 02139

7.2.4 Undergraduate Research Opportunities Program

UROP (almost pronounced Europe) is an exceptional program created for undergraduates at MIT. It gets special mention in this proposal because it has served as a valuable component in three areas of our research program: recruiting student talent, exploring high-risk topics, and increasing student-staff interaction. This program originated about eight years ago in order to encourage undergraduates to seek participation in ongoing research and to encourage faculty to devote the necessary time.

In UROP a student who works anywhere from 6 to 36 hours a week on a research project gets either credit or pay for that work. In cases where he is remunerated, this can be through either Institute discretionary funds or grant money (in the latter case, the grant is waived overhead on that money).

UROP is how, for example, we discover freshmen and sophomores who might otherwise not attend a seminar or subject until upper-class or graduate years. It is our most successful form of recruiting because (1) the student has the opportunity to "get to know" the researchers and (2) the research project does not need to risk funds (since in our case, we draw upon Institute monies for at least the first semester).

It is not unlikely that a "new" idea will emerge from a UROP project. While nine out of ten may be failures (except from the point of view of the student's educational experience), that one success is usually a winner and finds extensive subsequent support. To illustrate by example: last year a UROP student developed the scrolling idea that found its embodiment in our Xerox project (described in subsection 8.2.2, Informal Industrial Support).

A final note on student involvement in the spirit of UROP: it is the epitome of the both/and attitude. On occasion we will actually do the same project in two or three different ways at the same time.

7.2.5 Arts Program

In this final subsection of Educational Setting, we wish to share with the reader a growing interest for computers in the arts. The last appendix, "The Return of the Sunday Painter", dwells on one particular aspect of the future of computers in this area.

This emerging interest is part of a general concern for "professionalizing" the arts at MIT. While previously limited to cultural, humanitarian, and introspective goals, the MIT Arts Program is presently enjoying a push toward concentrated study and research at the graduate level. Research in the arts is truly a strange phenomenon, especially when it is presumed to go far beyond the technologies of making things.

Computational processes in general can be presumed to be one of the future art forms, perhaps so ubiquitous, that we will no longer distinguish it (art) from daily living. In the shorter range, we can see that computers have the important effect of merging the performing and the fine arts, previously quite separate with the rare exception of some modern operas, kinetic arts, and celebrations. Additionally, it is not hard to speculate on a process/product script in which the art would become the process of making it. Call it soft art.

The Principal Investigator is currently chairman of the Arts Steering Committee and that may be enough to justify these few paragraphs and their intrusion. However, beyond personal interests, we offer the art paradigm as a distinguishing feature of our laboratory and what makes it tick. If the result of conversation theory is anywhere near as rich as the authors of this proposal are beginning to believe it might be, then to view it as an exercise in artistic expression is not a tangential impression, but "right on."

7.3 Research Environment

This is the section in which we are supposed to explain to you how well-endowed our facility is and, if the work is judged important, why we are the only place it can be done. However, instead of emphasizing notions like critical mass, center of expertise, and the like, we will dwell upon the setting as it pertains to MIT at large, rather than to a room full of minicomputers, displays, and their extremities.

The topics discussed below emphasize both our permeation across departmental and laboratory boundaries and our laboratory's position as a cynosure for graphical interaction with computers.

7.3.1 Relationship to Other MIT Laboratories

Seven MIT laboratories and centers are directly related to our current activity and to the work proposed herein. They include:

The Laboratory for Computer Science
The Artificial Intelligence Laboratory
The Center for Advanced Engineering Study
The Center for Advanced Visual Studies
The Visible Language Workshop
The Film/Video Section
The Research Laboratory of Electronics

The Laboratory for Computer Science (LCS), formerly Project MAC, is MIT's largest center for computer research. LCS consists of 270 members -- 30 faculty, 80 support and professional staff, 130 graduate, and 30 undergraduate students -- organized into 13 research groups. They have two affiliate member groups: music and architecture (*i.e.*, us). As part of LCS we enjoy the availability of more "hard-core" computer science input from seminars, meetings, and informal encounters. At this time we receive modest funding through LCS, 2/3 full-time equivalent and, indirectly, funding through IBM for media research. The affiliation with LCS is listed first because it dates back to the mid-sixties and the days of the Kludge.

The Artificial Intelligence (AI) Laboratory goes almost as far back, primarily through the personal and invaluable contributions of Professors Marvin Minsky and Seymour Papert. In fact, our first proposal to NSF, *Machine Recognition of Models of the Physical Environment*, was a direct result of work done by us at the AI Lab on the (in those days) PDP-6. At this writing, the more formal exchanges are limited to invitations to lectures in one another's classes and student cross enrollment. However, the formal exhanges are supplemented by informal gatherings. We do share the common interest in personal computers. Although our LISP is limp, we do support two versions of LOGO, one on the calligraphic devices and the other on the color raster scan display. LOGO has served as an introductory vehicle for architecture students wishing to get immediate hands-on experience with computer graphics.

The Center for Advanced Engineering Study (CAES) is our landlord inasmuch as we occupy the top floor of their building. Besides the relationship through real estate, we share facilities and interests in video. A Sloan Foundation grant has been instrumental in forming an MIT cable television system and a high-quality television studio facility within CAES (in fact, in the basement of our building). This facility has been an important force in our video-based graphics. On several occasions we have provided the service of transmitting video signals directly from the computer to the campus at large via the cable. More importantly, on a technical basis we have had the opportunity to experiment with equipment that would otherwise be unavailable (for example, two-inch quad video tape recorders). At this writing, a second wave of requested Sloan money has a small portion allocated to strengthen this *ad hoc* relationship.

The Center for Visual Studies (CAVS - not to be confused with CAES) is most active in "video art." They currently have a Paik ABE Video Synthesizer with which we can communicate via the abovementioned cable. It is also the case that CAVS is mostly comprised of Fellows - artists in the prime of their careers. Two of the Fellows have been active and regular users of our color computer graphics.

The Visible Language Workshop (VLW) is a new and smaller operation. It is included because it is growing and will continue to grow into computer composition and direct, large-scale, color hard-copy output. Two vintages of our earlier graphics hardware (one color and one black and white) have migrated to the VLW and serve as the beginning of the group's own computer facility for which we plan to offer storage, cross-compilation and video input. A chance exists that VLW will acquire a PDP-11, in which case, a more up-to-date satellite facility will serve to generate formidable hard copy. Additonally, we have Mergenthaler Corporation to make available a computer composition system (either their VIP or a CRT machine) for joint usage.

The Film/Video Section is a partner in the "Conversational Video" project proposed to the National Endowment for the Humanities, described in subsection 8.3.3. Much of their work is moving into video from a previous concentration on research and development in professional super-8 sound-sync.

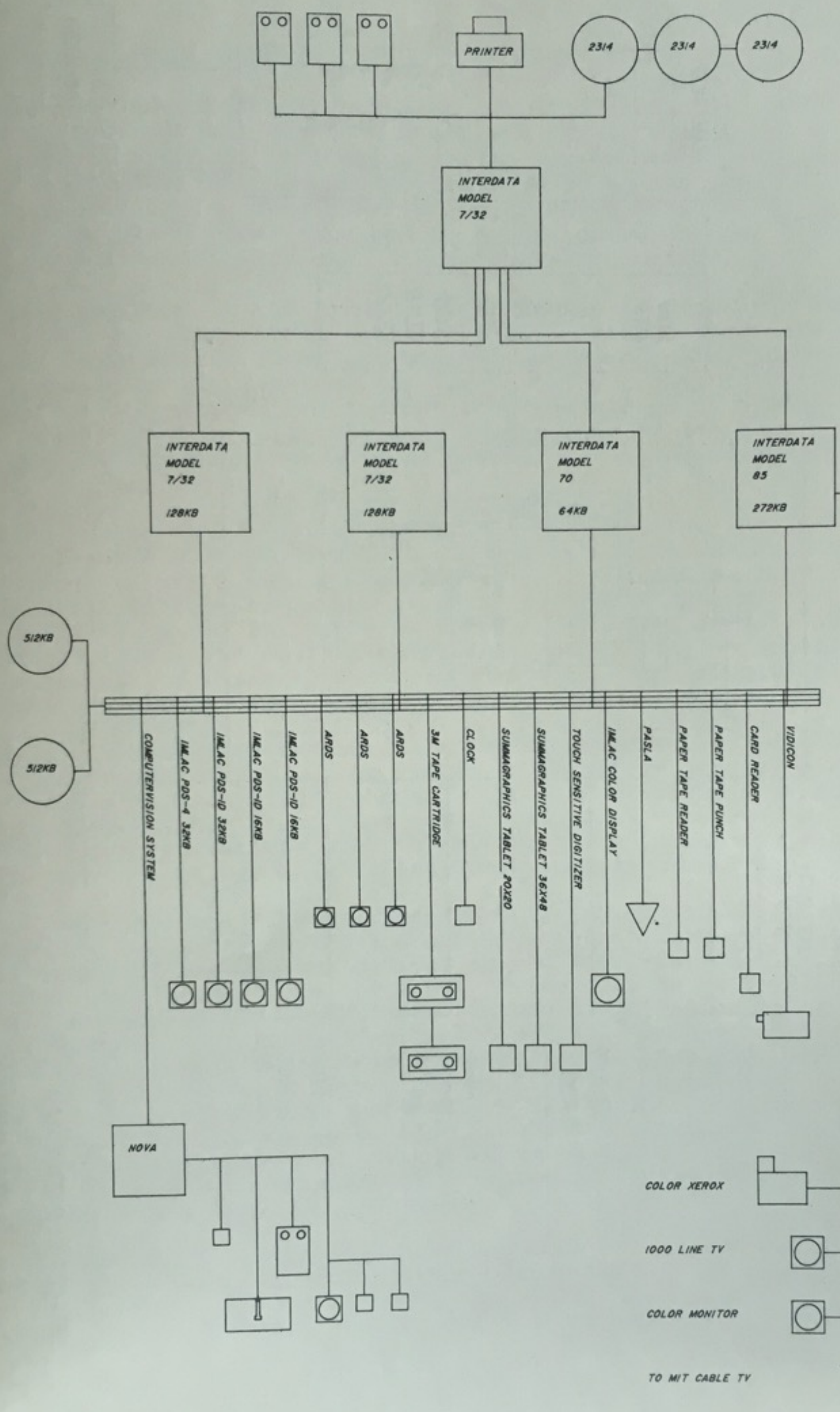
Finally, mention is made of the Research Laboratory of Electronics (RLE) a mention that should be more complete. While two of our staff come from previous employment at RLE, it is fair to say that our relationship to them has been weaker than it ought to have been. Recently, and with some formality, interest has been expressed in collaborating on hardware developments.

7.3.2 Hardware Facilities

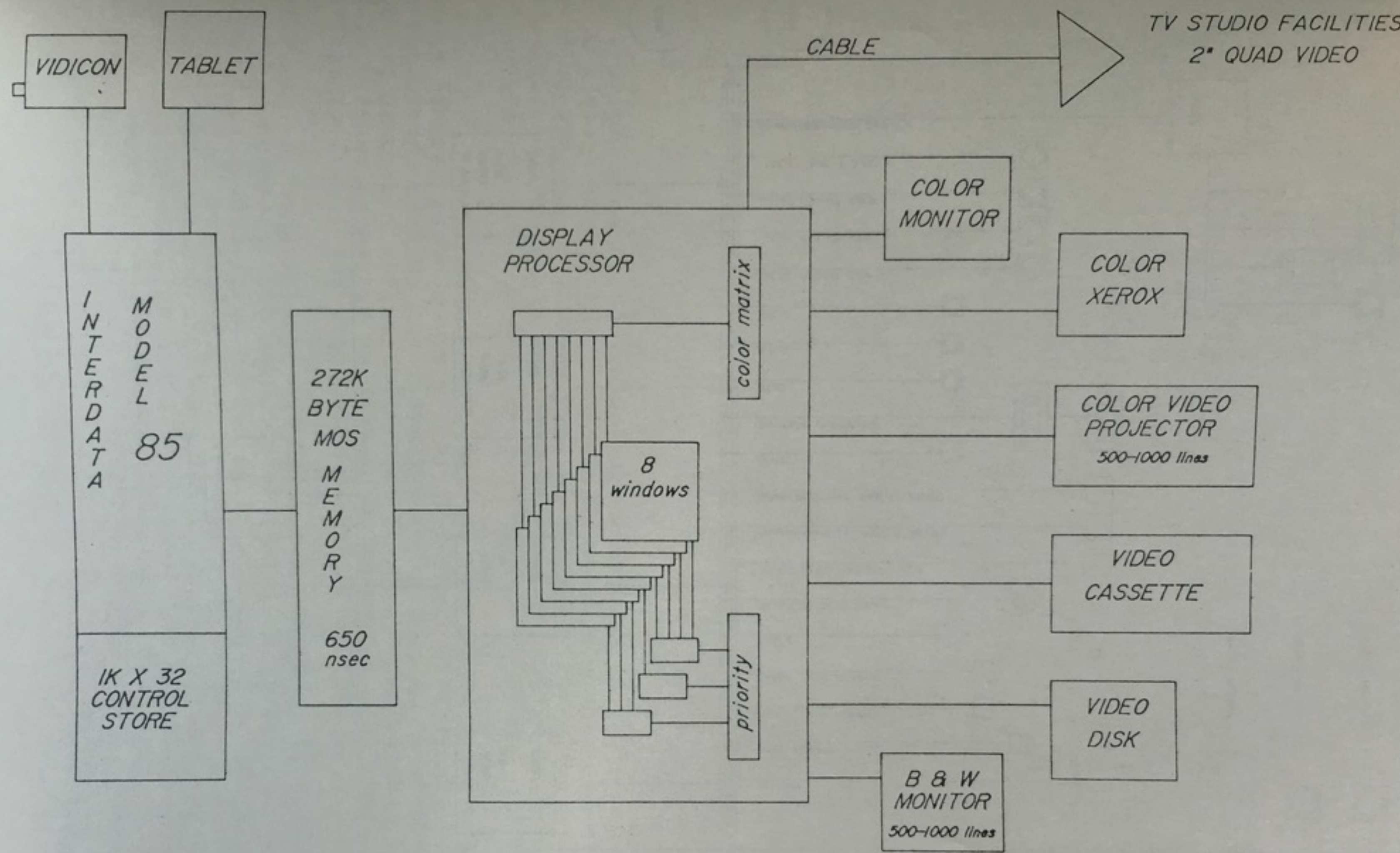
The evolution of our computer hardware is simple. In 1968, with the first storage tube (611, ARDS) ever delivered, a Sylvania tablet, and one of the first Interdata minicomputers, we built an "intelligent" terminal configuration for the 360/67. Over time this grew: paper tape, input/output, magnetic tapes, more core, a disk, a printer, and plotter, more core, and so on. By 1970 over $100,000 worth of peripherals hung on a single (approximately $15,000) minicomputer and, to no surprise, we were doing everything locally -- not using the 360 (or MULTICS) for anything.

This lopsided configuration was remedied with the (then) clever idea of a shared bus. This allows one device to be shared by several computers (with the problem of record-oriented input/output mentioned in subsection 5.1.5, Hardware). A limitation not mentioned in that subsection is that the shared bus is also limited to four minicomputers because at the time we did not expect to be able to afford more than four.

The following two pages diagram our facility. The first illustrates the overall configuration. The second diagrams the 85 raster scan display, mentioned on numerous occasions in this proposal. The ensemble is one of the largest research networks for the study of interactive graphics (Xerox PARC is the only other place comparable in both spirit and fact).



PRINTER
2314
2314
2314
INTERDATA MODEL 7/32
INTERDATA MODEL 7/32 128KB
INTERDATA MODEL 7/32 128KB
INTERDATA MODEL 70 64KB
INTERDATA MODEL 85 272KB
512KB
512KB
COMPUTERVISION SYSTEM
IMLAC PDS-4 32KB
IMLAC PDS-1D 32KB
IMLAC PDS-1D 16KB
IMLAC PDS-1D 16KB
ARDS
ARDS
ARDS
3M TAPE CARTRIDGE
CLOCK
SUMMAGRAPHICS TABLET 20X20
SUMMAGRAPHICS TABLET 36X48
TOUCH SENSITIVE DIGITIZER
IMLAC COLOR DISPLAY
PASLA
PAPER TAPE READER
PAPER TAPE PUNCH
CARD READER
VIDICON
VIDEO BUS
NOVA
COLOR XEROX
1000 LINE TV
COLOR MONITOR
TO MIT CABLE TV



VIDICON
TABLET
INTERDATA MODEL 85
IK X 32 CONTROL STORE
272K BYTE MOS MEMORY
650 nsec
DISPLAY PROCESSOR
color matrix
8 windows
priority
CABLE
TV STUDIO FACILITIES
2" QUAD VIDEO
COLOR MONITOR
COLOR XEROX
COLOR VIDEO PROJECTOR
500-1000 lines
VIDEO CASSETTE
VIDEO DISK
B & W MONITOR
500-1000 lines

7.3.3 Current Software Support

The current software at the Architecture Machine consists of the MAGIC operating system, several language compilers and interpreters, two text editors, several graphics systems, and a number of other programs which make life easier than if one were programming on an undiluted CPU. The system is largely an in-house development although it is based on the early vendor-supplied paper tape operating system which does allow us to use vendor-supplied software such as the FORTRAN compiler.

Most programming done at the Architecture Machine is done in a subset of the PL/I language. The subset has almost all of the control and program-structuring features but lacks the business-oriented data types (e.g., pictures) and currently lacks all of the PL/I input/output features since they are ill-adapted to interactive programming. A number of systems programs are written in PL/I (the link-editor, one of the text editors, and the LOGO interpreter), as well as almost all of the applications programs.

In addition to the PL/I compiler there is a LOGO interpreter, a LISP interpreter, and a FORTRAN compiler. LOGO is a simple language that allows novices to write simple programs without a great deal of instruction. The LISP is a small subset of MACLISP, but it can still be used to develop small systems: for example, to test out ideas on data organizations and the like. The FORTRAN compiler is still used on occasion, often to take advantage of existing software that was developed before the arrival of PL/I within newer programs.

The operating system itself supports a small multidirectoried file system, a device-independent input/output system, a primitive overlay management system, and a simple command processor. It also provides a substrate that is used to support that static and raster graphics systems as well as the PL/I runtime memory, but the user is able to "wire" (that is, make core-resident) many of the normally "transient," loaded-on-call system routines.

The basic and completely device-independent graphics system is referred to as the "static graphics" system and provides the ability to create static drawings on any of the various devices in the lab. In addition, it allows points to be read from any of the input devices. A newer version of this system was written in PL/I and allows picture modification on those devices that support it as well as better multiple screen support. Interestingly, the PL/I version is not much larger than the older assembler language version. There is also a raster graphics system that currently consists of a number of microcode overlays and an interrupt-driven control program that allows changes to be made to the TV controller's configuration (for example, changing the contents of color matrix). This system is being expanded to allow for the support of a number of different "flavors" of raster graphics displays.

The current operating system does have a number of disadvantages. It is based on sixteen bit minicomputers that necessitate relatively arcane methods of managing overlays and also limit the size of data bases that can be kept in core memory. The current file system was originally designed for use with a fixed head disk which had a very small sector size. This makes the file system sluggish at times. The current system also lacks any multitasking facility. Thus the applications program is required to manage its own time slicing in order to implement background and foreground tasks.

With the development of the Interdata n/32 (n = 7,8) series thirty-two bit minicomputers, the Architecture Machine was offered the option of taking advantage of the new hardware to solve a large number of the sixteen bit minicomputer problems. The new machines support a sixteen-bit-machine emulation-mode and so are being used as both sixteen and thirty-two bit machines during the transition period. So, for the past year and a half, a new version of MAGIC has been under development and is now nearing completion.

The new operating system was designed from scratch so that many of the flaws in the old system could be eradicated in the transition. It uses the full capabilities of the thirty-two bit hardware and the Interdata memory access controller. It provides a multitasking system with dynamic linking facilities (to simplify the overlay structure), segmentation (for support of pure procedures and shared data bases in multiple tasks), and a new file system that can take advantage of the larger, though slower, disk drives. The new system will initially support the PL/I compiler, a macroassembler, and the new text editor as well as an initial repertoire of file system and miscellaneous commands and subroutines.

The new graphics system will be designed to be a good deal more flexible than the old one. It will be designed to support a broad class of graphics devices ranging from highly structured ones (such as IMLACs) that allow a good deal of dynamicism, to relatively unstructured ones such a slow raster scan displays. In addition, it will be able to support remote machines and interprocessor communication so that applications can be run in machines with special purpose hardware and perhaps with instruction sets that are different from that of the central machine. This will allow us to support the requisite variety of specialized computers, which can then be used to provide highly interactive systems. This specialization will allow for computers that are simply microcomputers supporting demanding devices as well as machines that will perform large disk-based data manipulations.

The current software has both a large number of features and has been "housebroken" in the sense that the features that do work, work well. The new system will need to go through a long breaking-in phase although the initial switchover (during which work in progress will be moved from the old system to the new) is to start early in the first quarter of 1977. Although the new system will initially lack many of the amenities to which current users have become accustomed, it will acquire most of them as they are needed. By late in the year, most of our researchers should think of the new system as home.

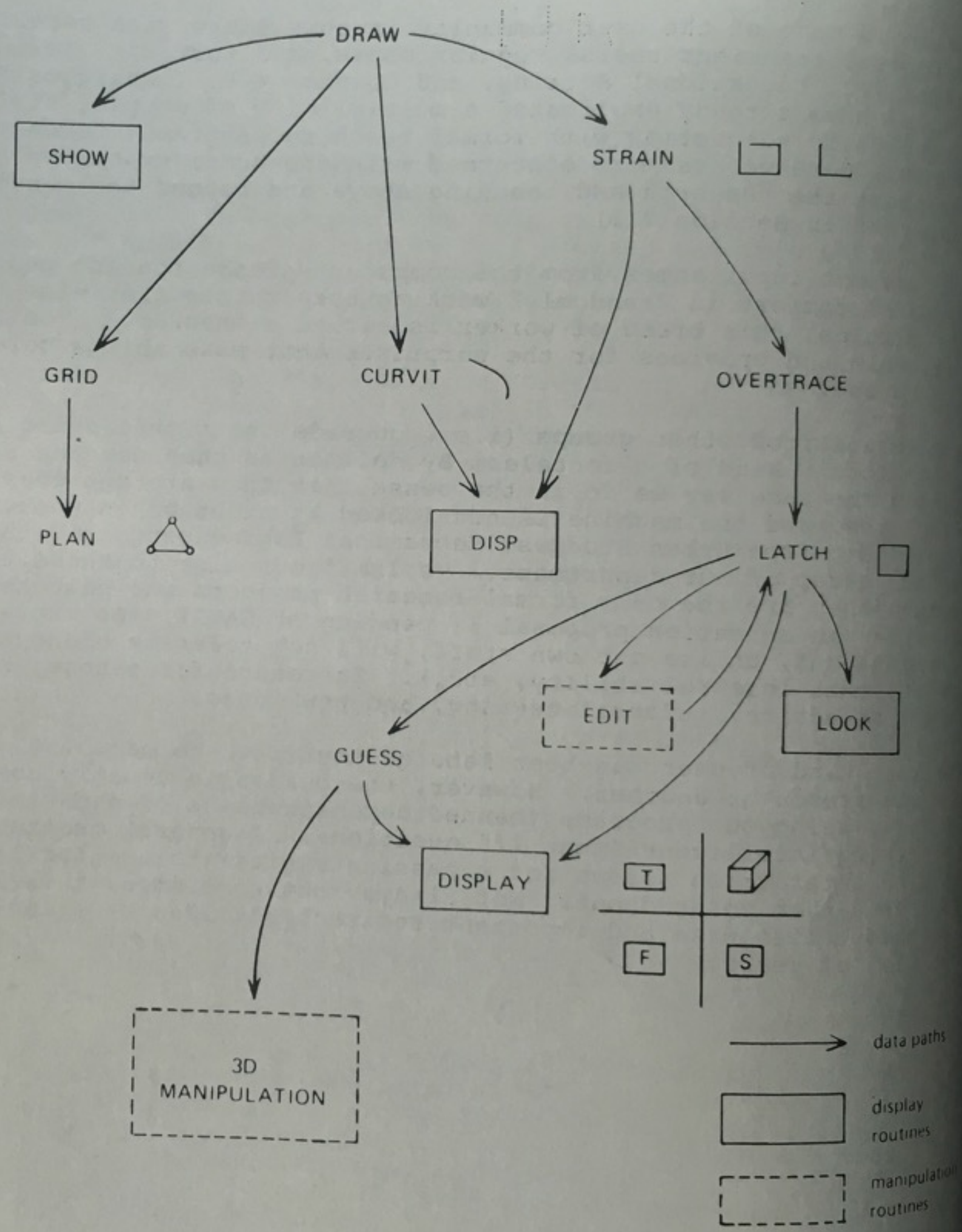
7.3.4 Local User Community

Mention is made of the user community in this subsection because the developers, transient users, regular users, and tourists are intermixed. Section 7.2, Educational Setting, and Chapter 4.0, Techniques and Methods, have already explicated a multiplicity of people, styles, and approaches in connection with formal teaching programs, research staff, or UROP. Here we are more concerned with the human resources available to support the research and teaching above and beyond the personnel (mentioned in Section 7.1).

Most salient input comes from the computer science student who finds a degree of comfort in "randomly" working here rather than elsewhere. In some circles, this breed of worker is called a "hacker." Their work is invaluable and provides for the surprises that make things more pleasure-able to use.

Researchers from other groups (i.e., outside the Architecture Machine group) form a kind of clientele. By definition they use the system in exactly the same way we do in the sense that they are not charged, sign-up is open, and the machine is not locked at night or on weekends. These people come from Urban Studies, Mechanical Engineering, and the Design Methods group of our department. We limit our list to these three because they are the only formal research projects who partake in the resource (an animation proposal is pending at CAVS). As users they are demanding and, unlike our own staff, will not tolerate changes (without notice, that lose reliability, etc.). In return for access, we get very objective advice, informal testing, and new ideas.

The last kind of user has been labeled tourist. We have too many visitors for one reason or another. However, the burden is usually compensated for by their using our programs (canned demonstrations of one kind or another) and asking intelligent "what if" questions. A general excitement and genuine interaction allows for a passing visitor to use facilities rather than have them pointed out. Not always, but sometimes, this leads to insightful discourse and important redirection. Hence we include them in our list of users.



The HUNCH System

8.0 CONCURRENT SPONSORED RESEARCH

8.0 CONCURRENT SPONSORED RESEARCH

This chapter is dangerous to our case. On the one hand, we would like to convince you that we have a well-balanced research program, intermixing grants and contracts, basic and mission-oriented work; on the other hand, we do not want to portray a lushness that suggests NSF support is not necessary. In fact, without it, the following projects, planned or existing, would deteriorate or perhaps disappear. With the exception of modest support from the Office of Naval Research, concurrent projects are in no sense basic studies. They have pragmatic goals and pragmatic program directors who expect well-defined products.

This proposal goes hand in hand with the presumption that it would enjoy a similar balance.

8.1 Federal Support

We currently receive federal support from three sources: The Advanced Research Projects Agency (ARPA), The Office of Naval Research (ONR), and The Army Research Office (ARO). Additional and small support has been received from the Air Force to design and install very specific IMLAC software, which is not mentioned in that it did not result from an RFP or unsolicited proposal, but from an existing MIT-Air Force agreement.

The following three subsections are reprints of the respective abstracts. Here we briefly dwell on the project's relationship to this proposal, in the event that it is funded.

The ARPA work in spatial data management is a *direct* application of intra-personal conversation. The underlying idea is that humans tend to manage many kinds of data, especially personal information, spatially. This is seen on desk tops, in filing cabinets, and on bookshelves. Additionally, we observe that people tend to use sound and color as important cues. (In your own book collection, how many books do you know by the colors of their covers? How many by their exact positions on the shelf?) The contract with ARPA is to apply simple spatial principles to a nonsymbolic data management system where the storing of data would be akin to building a city, and the retrieving of it would be much like traveling through a city (maybe even sightseeing). This work relates intimately with the tacit assumption that personalization is the key ingredient to interaction and mediation.

ONR, in contrast, treats personalization as more than a tacit assumption. Personalization is the basis of the ONR work. The application is currently in computer aids to technical writing. The theme is described by the slogan: writing in camera copy. The idea for this particular application for idiosyncratic systems stems from the observations (perhaps personal) of a deterioration of writing style in the presence of a text editor. The absence of many of the dimensions of paper -- drawing on it, working in two dimensions, crumpling it -- are sorely missing but are part of work styles. Are these work styles learned such that they can be relearned (and circumvented) or are they deep-rooted psychological constructs that form part of the content of our writings?

The ARO work relates to this NSF proposal as a formal counterpart to the informal agenda for color research. ARO is interested in very specific applications of color, for the most part in mapping. Can color compensate for resolution in a raster scan environment? Can humans discriminate equi-hue, equi-saturation, and equi-intensity?

8.1.1 ARPA

The following text is the original ARPA abstract, as submitted. Subsequently the theme became a data management scheme rather than a command and control system.

ABSTRACT:

Augmentation of Human Resources in Command
and Control through Multiple Media
Man-machine Interaction

The following pages outline a two year agenda for research into multiple media interaction between man and computer. While specific research already has lead to developments in a variety of channels and dimensions of computer input and output, no work exists that assembles, intermixes, and evaluates multiple modes and media potentially in operation at the same time. The first year of experimentation exercises a prototype terminal. The second year elaborates the work into the notion and implementation of a place: a media-intensive, computer-based workspace. Throughout, selected experimental tasks will be addressed to specific issues concerning man-computer interaction in the multiple-media environment. Each year includes a $50,000 line item for on-demand experimentation to be specified in concert with HRRO on a bi-monthly basis. The total task is specified at an average level of under $300,000 per year.

Multiple Media
Man-Machine Interaction

8.1.2 ONR

The following abstract was included with our August 1975 proposal to ONR as an application of the previously supported studies of "idiosyncratic systems."

ABSTRACT

The objective is to assist and augment technical writing through advanced computer techniques, particularly computer graphics. Goals include facilitating the task of input, improving the content, style, and graphic design of output, and making the writing process more versatile, creative, and personal. This is an application of what we call an "idiosyncratic systems" approach to man-computer interaction. We postulate that current computer text editors, largely one-dimensional, are stultifying, prolifer-ate unanimated documents, and impair writing styles.

Techniques and systems aimed at meeting these objectives are applications of previous ONR work in computer graphics. Military relevancy resides in the formidable document preparation tasks in DOD.

8.1.3 ARO -- Understanding Color in Displays

The following text introduced our January 1976 proposal to The Army Research Office (ARO). The proposal was subsequently modified to include extensive reference to previous work and specific experimentation, namely studies in equi-hue, equi-saturation, and equi-intensity as discriminatable overlays in mapping. The following is included for the reader to appreciate a partnership with more formal and specific studies or color theory.

STATEMENT OF TASK OBJECTIVES

The objective is to analyze and test various relevant psychophysical data on color perception as to their applicability in a color display system. Quantitative studies on such phenomena and newly devised experiments with many subjects will provide information as to how color displays may be evaluated and enhanced as transmitters of data in graphic form to the human visual sink. Using an existing real time, on-line, color computer graphics facility, we feel that a high-quality color television monitor may be used to simulate a wide variety of color displays.

In using color to code and enhance data, it is vital to quantitatively understand the relationship between the appearance of a color in a complex spatial environment and its specified chromaticity. We feel that design guidelines can be drawn up to determine engineering criteria to be considered in specifying and optimally utilizing a color display system with regard to fatigue, legibility, accuracy, ambient conditions, and effectiveness in communicating graphical information.

8.2 Industrial Sponsorship

MIT has a well-run, energetic, and far-reaching Industrial Liaison Program that currently has one-hundred and eleven American members (see list below). Through this office we have been able to visit or receive visits from over thirty companies which are directly related to the computer industry. In some cases, these interludes result in pleasant and interesting conversation. In other cases, we receive direct hardware support. In still other cases, it is the beginning of specific funding.

Additionally, we have developed close ties with smaller companies, not part of the *Fortune* 500, but important to the computer community. These are articulated in subsection 8.2.2, Informal Industrial Support.

AMP Incorporated
Abex Corporation
Addressograph-Multigraph Corporation
The Aerospace Corporation
Alcan Aluminium Limited (Canada)
Allegheny Ludlum Industries, Inc.
Aluminum Company of America
American Can Company
American Cyanamid Company
American Electric Power Company Incorporated
American Maize-Products Company
Amsted Industries Incorporated
Atlantic Richfield Company
Avco Corporation
BASF Wyandotte Corporation
Beatrice Foods Co.
Becton, Dickinson and Company
Bell Telephone Laboratories, Incorporated
The Boeing Company
Borden, Inc.
Borg-Warner Corporation
Boston Edison Company
Buckeye International, Inc.
Burroughs Corporation
CPC International Inc.
Cabot Corporation
Campbell Soup Company
Carnation Company
Caterpillar Tractor Co.
Celanese Corporation
Champion International Corporation
Citibank
Control Data Corporation
Dayton-Walther Corporation
E. I. du Pont de Nemours & Company Incorporated
Eastman Kodak Company
Envirotech
Exxon Corporation (Exxon Research and Engineering Company)
Florasynth, Inc.

Formsprag Company
The Foxboro Company
General Dynamics Corporation
General Mills, Inc.
General Motors Corporation
General Telephone & Electronics Corporation
The Gillette Company
The Goodyear Tire and Rubber Company
Gould Inc.
Grumman Corporation
Hercules Incorporated
Hershey Foods Corporation
Hoffmann-La Roche Inc.
Hughes Aircraft Company
International Business Machines Corporation
International Telephone and Telegraph Corporation
Jewel Companies, Inc.
John Hancock Mutual Life Insurance Company
Johnson Controls, Inc.
Johnson & Johnson
Kennecott Copper Corporation
Kerr-McGee Corporation
Kimberly-Clark Corporation
Leeds & Northrup Company
Liberty Mutual Insurance Company
Arthur D. Little, Inc.
Litton Industries Inc.
Lockheed Aircraft Corporation
P. R. Mallory & Co. Inc.
Marathon Oil Company
Martin Marietta Corporation
McDonnell Douglas Corporation
Mobil Oil Corporation
Morgan Guaranty Trust Company of New York
Motorola, Inc.
Nabisco, Inc.
National Distillers and Chemicals Corporation
Naval Air Development Center
New England Electric System
Norton Company
Occidental Petroleum Corporation
Owens-Corning Fiberglas Corporation
PepsiCo, Inc.
Pfizer Inc.
Phelps Dodge Industries Inc.
The Procter & Gamble Company
RCA
Raytheon Company
R. J. Reynolds Industries, Inc.
Rockwell International Corporation
SCM Corporation
Sanders Associates, Inc.
Sears, Roebuck and Co.

Shell Oil Company
The Singer Company
Sperry Rand Corporation
Sprague Electric Company
Standard Oil Company of California
Standard Oil Company (Indiana)
Stewart-Warner Corporation
Stone & Webster Engineering Corporation
TRW Incorporated
Texaco Inc.
Texas Instruments Incorporated
Textron, Inc.
The Timken Company
UOP, Inc.
USM Corporation
Union Oil Company of California
United States Steel Corporation
United Technologies Corporation
Vought Corporation
Western Union Corporation
Westinghouse Electric Corporation
Xerox Corporation

8.2.1 IBM -- Computer Animation

The proposal to IBM included several aspects of computer graphics, but heavily emphasized computer animation. The following text is an overview of two systems under development.

Two animation experiments would launch the research. The first is a set of experiments based on the conviction that computer animation offers a totally unique medium for art and education. No other medium can provide a conceptual space in which to explore the fundamental relationships between form and content, process and product. The simulation environment, interactive and fast feedback qualities, and pure information processing capabilities of the computer provide this conceptual space. Grasping these powers in the process of creativity will demonstrate the clear distinction between "computer output" and "personal computer output."

These assumptions direct the research toward an animation system environment with interaction on two distinct conceptual levels: the *process* space, the user's "way of thinking about it" conceptually; and the *visual* space, which is the output, i.e., the product of the user's efforts. The essence of the system is the ability to input and modify in *both* spaces. Drawing figures and specifying paths of motion in the visual space is followed by viewing a machine-generated description of the sequence much like process-control. This "process description" can be modified and the resulting change to the visual space can be immediately viewed (with only a pause for computation). A change can be made in the visual space, and so on. This iteration between process and product, conceptualization and visualization, form and content, should prove exceptionally instructive, if not thrilling, for the child, parent, or professional animator.

Exploration of the process space will be by means of a graphical interactive editor, perhaps a touch sensitive display. Essential elements will be user-configurable system, extensibility, and embedded/interface capabilities. This last feature will extend the idea of allowing a user to work in whatever conceptual space is most comfortable. Instances where mathematical or "scripted" descriptions are the most facile for the user will not be refused; even PL/I can be interfaced without losing the general interactive qualities which the system as a whole provides.

Subsets of the system that provide complete simulation environments can be constructed from the proposed system. One could offer a student a Newtonian space which he could explore interactively, changing examples and rules at will. This is a new dimension to computer-aided instruction where only that which can be predicted can be handled. Here the student is offered an "environment," which is totally modifiable *and* which provides a level of explorative interaction known only in one-to-one, teacher/pupil situations of the Socratic type. The interaction between the description of a conceptual space, and the consequences of the defined laws of a system, is a feedback-loop of student-defined problems that provides "teaching" in the richest, most personal sense of the word.

The second animation experiment is both briefer and more modest in its need for interactive paraphenalia. Let us temporarily call it a "keyboard-driven" animation system. In a formal sense, closely aligned to the spirit of theater, we envisage a "script" with "actors." A "scene" is literally the control structure that relates the two over time.

This second exercise is almost the antithesis of the first and is included for that reason. The risk (which we shall do our best to avoid) is that the second departs into an opaque formal grammar only manageable by the sophisticated (and patient) linguist. In comparison, the first is closer to handwaving and doodling, everybody being his own Toscanini. We look forward to the interplay between these two efforts as yielding the true innovation in television-based computer animation.

8.2.2 Informal Industrial Support

The term "informal" refers to support that is not the result of a written proposal and is without specific task or deliverables. This kind of arrangement ranges from the manufacturer who gives a 50 percent discount because he feels that MIT or our lab or both, would make a nice showcase for his product, to the company that provides annual discretionary or fellowship support for being in on the "action."

Without dragging this subsection through the plethora of wheelings and dealings that have helped us build up a research facility and to multiply the scarce capital equipment funds, we dwell on the industries from whom we not only obtain support (real money or hardware), but from whom we receive important intellectual input. These include:

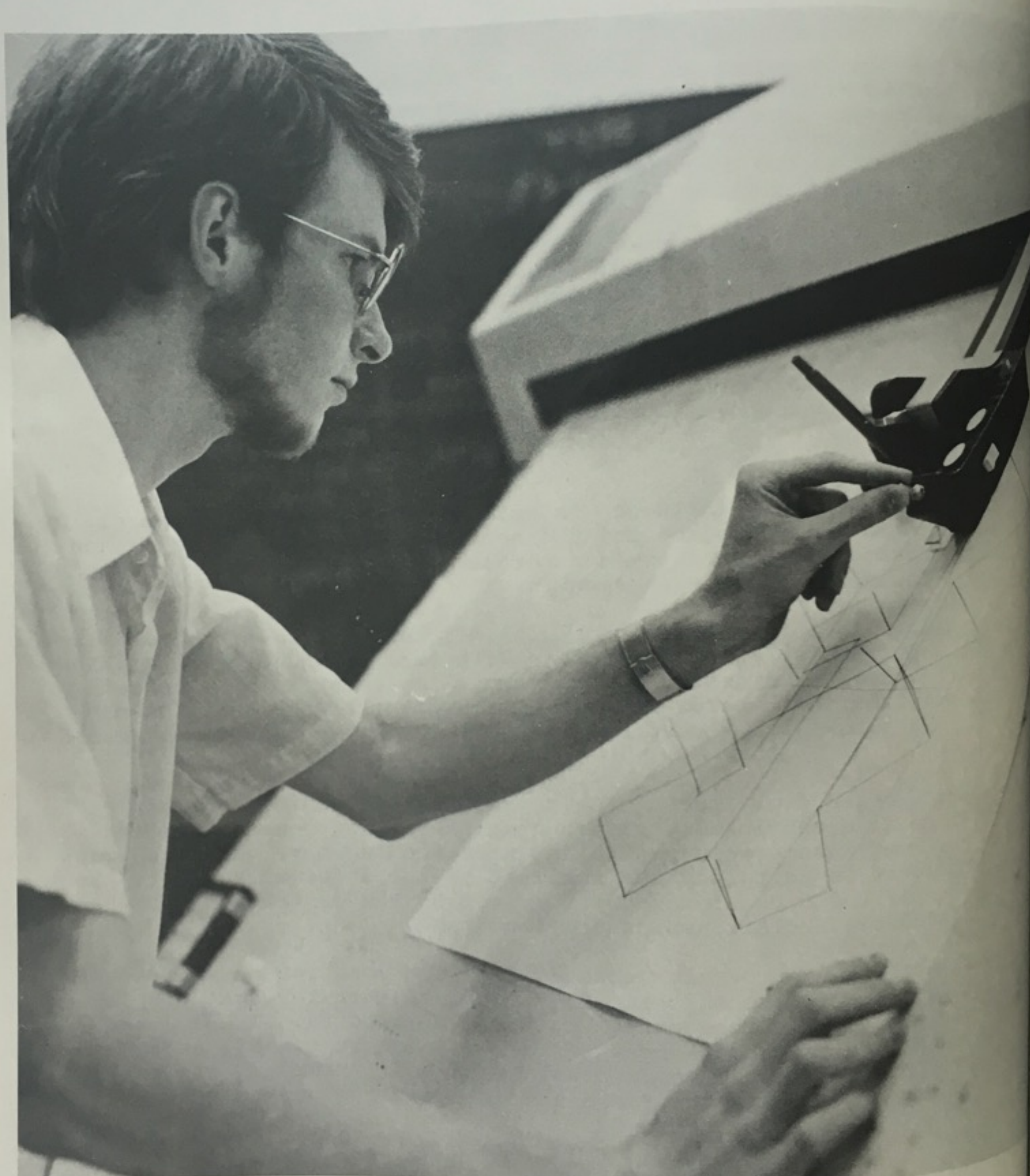
Bell Northern Research
Computervision Corporation
Summagraphics
Ramtek

Bell Northern Research's influence is well-displayed in this proposal. Scribblephone is their product and the notion of shared graphical space is their concept. We have enjoyed numerous exchanges and direct support that has allowed for major expansion in video.

Computervision had a formal contract with MIT last year, which ended in June 1976. Currently, our relationship with them is an informal exchange of ideas on interactive design. Our current implementation of force feedback utilizes their hardware. Other equipment of theirs is on consignment. It allows for students of architecture to engage in automated drafting.

Summagraphics makes digitizers. Their president and chief engineer happens to be an exceptionally gifted and interesting person, through whom we have met innumerable people and with whom we have generated many ideas. While it is certainly the smallest of the informal supports, it has been one of the richest encounters, proving the contention that informal industrial relationships are important.

Ramtek is included last partly because it is the most recent engagement of this kind. It centers on their 9300 machine, a raster scan display system very similar in architecture to our over-used 85. It has been running in the lab for about three weeks and hence we cannot report either specific successes or conceptual exchanges. However, their product enjoys longest standing in the field and future plans are enthusiastic.



8.3 Planned and Concurrent Proposals

The proposals range from being "in the back of our minds" to "about to be accepted." Four subsections are included -- mostly in the spirit of demonstrating good intentions. In our earlier (1973) interaction with NSF there was a concerted interest by NSF to see their research moved "into the field." The previous two subsections illustrated this in the present tense, the following are included as a foretaste of the future.

8.3.1 NSF and ERDA -- The Intelligent House

This proposal is characteristic of "in the back of our minds." In large measure, it can be presumed to be the applications component of our current NSF work, moved out of this proposal, into an applications setting. The following text was forwarded to ERDA at the beginning of November.

Micro-processors are finding their way into refrigerators, ovens, thermostats, and telephones. Computer memory has dropped from $1.00 per bit to less than $0.001 in ten years. Computer graphics has noticeably moved into television based technologies. These three facts point to the marriage of the computer and the consumer, namely, the computer at home. However, most people view this as a device or a console, akin to furniture, with which one plays, works, and supervises daily life.

In contrast, this proposal is more pervasive. It considers computational properties, distributed much like electricity and plumbing, likened to process control systems familiar to refineries, factories, and some high-rise buildings. But it is more than super-instrumentation; it includes personalized, suggestive, and interactive systems as part of the orchestration of otherwise separate and discrete processes.

We see every wall as a display, every switch as an ear, every power source as a purposeful system. This proposal is aimed at segregating the fiction from the fact, outlining cost-effective and realistic application of a computing resource and management system in homes of the future. We have discussed this work with the National Science Foundation. A proposal will be submitted to them for the computer science component of this work, to begin in November 1977. The attached budget is for the purpose of preparing a report on the energy-related implications of such a venture. We would plan to submit a proposal to ERDA at the same time as NSF for consideration in joint funding, at a large level, for longer duration. The output of this second stage would be a prototype house.

8.3.2 ARI -- Continuing Color Studies

The Army Research Institute (ARI) is very different from ARPA, ARO, ONR, and other seemingly related Department of Defense (DOD) research branches. The difference hinges primarily on ARI's being a research, as opposed to a funding agency (though ARI does fund or subcontract basic research).

The proposal to ARO, previously described in subsection 8.1.3 found its way to ARI for review. This review process led to an ARI interest in a long-range association which we plan to pursue next year as part of a growing color group under the direction of Robert Solomon (whose curriculum vitae is in subsection 7.1.4).

We list this intention because we have not dwelled on basic color research to the degree that would be warranted in conversation theory. Our perception is that very few people understand color, especially as a psychophysical phenomenon.

8.3.3 NEH -- Conversational Video

The National Endowment for the Humanities (NEH) currently has a proposal before them to do conversational video. This results directly from the work of an NBC producer and an interest to do digital editing. Many of our interests in write-once memory come from this application. The abstract follows.

ABSTRACT

Conversational Video
A Resource for the Humanities

This is an eighteen-month proposal to implement a pilot project, the prototype of which would allow a student of the humanities to converse with an artist, scholar, or luminary not present, not necessarily alive. The notion is simple: given enough (for example, greater than 10) hours of properly directed film/video material, a user can interactively peruse the material, through a keyboard-driven question and answer session.

This proposal includes the use of computerized television technologies available only in laboratories, the result of and funded by other research, but presumed to be commonplace three to five years hence. Additionally, the proposed prototype will use material already developed for this purpose, namely forty hours of video tape on the sculpture Jacques Lipchitz prepared for two "living histories" presented at the Metropolitan Museum in New York in 1972 and the Corcoran Gallery in Washington, D.C., in 1975.

The reader is expected to understand the proposal as something which lies between Computer-Aided Instruction, common to the sciences, and the random access nature of a book, familiar to the humanities. The proposal is composed of three distinct parts:

1. Time-based indexing and a natural language interface
2. Random access video
3. A working prototype

8.3.4 IBM -- Media Room

As part of a larger MIT-IBM grant, we have submitted a proposal to build a so-called media room. This is in direct supplement to our ARPA "information surround" and the previously described task: "conversation place." The IBM funds would be used to build parts of the display system and sound system, otherwise prohibitively expensive. The following text is part of an informal letter proposal that was transmitted to the provost.

We propose to build a media room. The proposition results from a sequence of developments, funded in most part by prior IBM funds. In short: we have developed a full-color, television-compatible system for animation, mapping, and page layout. Currently, this color system is viewed through a 19-inch *window*, in the traditional genre of terminals. This proposal is to expand this *window* in two important ways:

1) The *window* is an entire room, in which the surround is integral to the "ambient information."

2) The room deploys multiple media, imbedding sound in three-space, having floor-to-ceiling display, and instrumenting force feedback systems.

This work is an extrapolation of conversations with Bernie Greenblott and is an extension of our current ARPA interest: Spatial Data Management Systems. The IBM funds would be used to implement and test innovations in user-computer interactions, primarily in the application I call "sound-sync animation."

The media room would have the following properties:

1) 7 by 10 foot, rear-projected display
2) four channel voice and sound output
3) 3-by-4-foot tablet input
4) a joy-stick driven force feedback mechanism
5) a touch sensitive portion of the display (2-foot square)

The first two items are part of capital equipment in connection with our ARPA work. The remainder are existing or the anticipated results of current UROP efforts. I see this proposal as an end-all of computer interfaces, something which we will be able to demonstrate, something *into* which IBMers can go and see.

The attached budget reflects parts or all of the salaries of two people. One, Paul Pangaro, is a continuation of a DSR Staff position he currently holds on our present IBM grant. The other, Andrew Lippman, is a graduate student in our newly created M.S. Program in Computer Graphics.

8.3.5 Discretionary Arts Support

This subsection is included to alert the reader of a formalization of what has been an implicit alignment with the arts. While the arts do not yet enjoy either endowment or research at MIT, they compose a group of extremely active and animated faculty surrounded by a sense of excitement. This excitement comes from a potential cohabitation of art and technology, much different and much richer than predecessors such as Experiments in Art and Technology (EAT).

The Film/Video Section, under the direction of Richard Leacock; the Center for Advanced Visual Studies, under the direction of Otto Piene; the late Minor White's photograph laboratory; and the recent Visible Language Workshop under the guidance of Muriel Cooper are all trying to come together into what could be a formidable program. We plan to be part of that program and have lent support whenever possible.

One of the mechanisms, not uncommon, to move in this direction is to raise discretionary or discretionary-like funds for the arts, to develop programs, research, and a graduate degree. This is happening. Ten foundations are being solicited by the Arts Steering Committee (Leacock, Piene, Negroponte). At this writing a great deal of optimism exists and we look forward to a three-year experimental program, during which time the art community would become yet heavier users of work such as that proposed in this document.

9.0 BUDGET

9.0 BUDGET

Our current NSF budget for the academic year 1976/1977 is $220,200. It is the third of three years, growing less than the rate of inflation to that figure. In many respects, the following pages are culled from experience with that budget. Items such as materials and supplies, travel, and publications are taken from retrospection. In most cases, increases in line items are salary increases, inflation, and contingencies. Our current work suffers from having not considered these appropriately in previous proposals. For example, since our first NSF proposal, employee benefits have risen from 16 percent (without overhead on it) to a current 24.5 percent (with 68 percent overhead on it).

9.1 Budgetary Overview

The budget has the following anomalies:

1. No charges are present for computer time.
2. Equipment charges are less than 12 percent, including the 1981 surge explained in section 9.4.
3. Faculty is seemingly low.

The latter is the result of Dr. Gordon Pask's current position as a consultant. If those funds were moved to the faculty line item, the imbalance would be, in some sense, in the other direction. As mentioned in section 7.2 we are proposing Dr. Pask for the newly created position of Adjunct Professor, specifically to participate in this research and to teach at least one seminar around this material.

9.2 Composite Five Year Budget

	7/1/77-6/30/78	7/1/78-6/30/79	7/1/79-6/30/80	7/1/80-6/30/81	7/1/81-6/30/82
Faculty	7,130	7,780	8,400	9,200	10,100
Staff	50,680	55,220	60,030	65,550	71,520
Benefits (24.5%)	14,163	15,435	16,765	18,314	19,997
Student Staff	35,000	39,800	44,700	49,900	55,300
Consultants	12,000	12,000	17,000	12,000	12,000
Materials and Services	24,000	25,200	26,500	27,800	29,200
Publications			2,500		3,500
Equipment	25,000[1]	26,000[2]	27,000[2]	50,000[3]	30,000[2]
Travel	6,500	6,800	7,150	7,500	7,900
Miscellaneous	1,000	1,050	1,100	1,150	1,200
Overhead (68%)	60,842	66,358	72,111	78,720	85,862
Total	236,315	255,643	283,256	320,134	326,579

Grand Five Year Total 1,421,927

9.3.1 1977-1978

		7/1/77-6/30/78
Faculty		
Academic Year		
Nicholas Negroponte (25%)	5,500	
Summer		
Nicholas Negroponte (33%)	1,630	
Subtotal		7,130
Staff		
Richard Bolt (10%)	2,700	
Robert Solomon (10%)	2,500	
Christopher Herot (90%)	15,840	
Paul Pangaro (10%)	1,540	
Seth Steinberg (100%)	15,500	
Bill Kelley (25%)	5,500	
Administrative Assistant (25%)	2,700	
Secretary (50%)	4,400	
Subtotal		50,680
Benefits (24.5%)		14,163
Student Staff		
Research Assistants (2.5)		25,000
4 Hourly Student Staff		5,000
5 UROP		5,000
Consultants		
Dr. Gordon Pask		12,000
Materials and Services		
Hardware Servicing	2,200	
EDP Supplies	4,000	
Electrical Supplies	6,000	
Mechanical Supplies	1,100	
Communications	1,700	
Office Supplies	3,000	
Printing Offset	1,200	
Xerox (B&W)	2,400	
Film and Video	2,400	
Subtotal		24,000
Publications 6		
Equipment		25,000
Travel		
Domestic	2,500 7	
Foreign	4,000	
Subtotal		6,500
Miscellaneous		1,000
Overhead (68%)		60,842
Total		236,315

9.3.2 1978-1979

		7/1/78-6/30/79	
Faculty			
Academic Year			
Nicholas Negroponte (25%)	6,000		
Summer			
Nicholas Negroponte (33%)	1,780		
Subtotal		7,780	
Staff			
Richard Bolt (10%)	2,940		
Robert Solomon (10%)	2,700		
Christopher Herot (90%)	17,300		
Paul Pangaro (10%)	1,680		
Seth Steinberg (100%)	16,900		
Bill Kelley (25%)	6,000		
Administrative Assistant (25%)	2,900		
Secretary (50%)	4,800		
Subtotal		55,220	
Benefits (24.5%)		15,435	
Student Staff			
Research Assistants (2.5)		27,300	
Hourly Student Staff		5,500	
UROP		7,000	
Consultants			
Dr. Gordon Pask		12,000	
Materials and Services			
Hardware Servicing	2,300		
EDP Supplies	4,200		
Electrical Supplies	6,300		
Mechanical Supplies	1,150		
Communications	1,800		
Office Supplies	3,200		
Printing Offset	1,250		
Xerox (B&W)	2,500		
Film and Video	2,500		
Subtotal		25,200	
Publications			
Equipment		26,000	
Travel			
Domestic	4,700		
Foreign	2,100		
Subtotal		6,800	
Miscellaneous		1,050	
Overhead (68%)		66,358	
Total			255,643

9.3.3 1979-1980

Faculty			
Academic Year			
Nicholas Negroponte (25%)	6,500		
Summer			
Nicholas Negroponte (33%)	1,900		
Subtotal		8,400	
Staff			
Richard Bolt (10%)	3,200		
Robert Solomon (10%)	2,900		
Christopher Herot (90%)	18,800		
Paul Pangaro (10%)	1,830		
Seth Steinberg (100%)	18,400		
Bill Kelley (25%)	6,500		
Administrative Assistant (25%)	3,200		
Secretary (50%)	5,200		
Subtotal		60,030	
Benefits (24.5%)		16,765	
Student Staff			
Research Assistants (2.5)		29,700	
Hourly Student Staff		6,000	
UROP		9,000	
Consultants			
Dr. Gordon Pask		12,000	8
Visiting Committee		5,000	
Materials and Services			
Hardware Servicing	2,400		
EDP Supplies	4,400		
Electrical Supplies	6,600		
Mechanical Supplies	1,200		
Communications	1,900		
Office Supplies	3,400		
Printing Offset	1,300		
Xerox (B&W)	2,650		
Film and Video	2,650		
Subtotal		26,500	
Publications		2,500	9
Equipment		27,000	
Travel			
Domestic	4,950		
Foreign	2,200		
Subtotal		7,150	
Miscellaneous		1,100	
Overhead (68%)		72,111	
Total			283,256

9.3.4 1980-1981

		7/1/80-6/30/81	
Faculty			
Academic Year			
Nicholas Negroponte (25%)	7,100		
Summer			
Nicholas Negroponte (33%)	2,100		
Subtotal		9,200	
Staff			
Richard Bolt (10%)	3,490		
Robert Solomon (10%)	3,160		
Christopher Herot (90%)	20,500		
Paul Pangaro (10%)	2,000		
Seth Steinberg (100%)	20,100		
Bill Kelley (25%)	7,100		
Administrative Assistant (25%)	3,500		
Secretary (50%)	5,700		
Subtotal		65,550	
Benefits (24.5%)		18,314	
Student Staff			
Research Assistants (2.5)		32,400	
Hourly Student Staff		6,500	
UROP		11,000	
Consultants			
Dr. Gordon Pask		12,000	
Materials and Services			
Hardware Servicing	2,500		
EDP Supplies	4,600		
Electrical Supplies	6,900		
Mechanical Supplies	1,250		
Communications	2,000		
Office Supplies	3,600		
Printing Offset	1,350		
Xerox (B&W)	2,800		
Film and Video	2,800		
Subtotal		27,800	
Publications			
Equipment		50,000	
Travel			
Domestic	5,200		
Foreign	2,300		
Subtotal		7,500	
Miscellaneous		1,150	
Overhead (68%)		78,720	
Total			320,134

9.3.5 1981-1982

		7/1/81-6/30/82
Faculty		
Academic Year		
Nicholas Negroponte (25%)	7,800	
Summer		
Nicholas Negroponte (33%)	2,300	
Subtotal		10,100
Staff		
Richard Bolt (10%)	3,800	
Robert Solomon (10%)	3,440	
Christopher Herot (90%)	22,400	
Paul Pangaro (10%)	2,180	
Seth Steinberg (100%)	21,900	
Bill Kelley (25%)	7,800	
Administrative Assistant (25%)	3,800	
Secretary (50%)	6,200	
Subtotal		71,520
Benefits (24.5%)		19,997
Student Staff		
Research Assistants (2.5)		35,300
Hourly Student Staff		7,000
UROP		13,000
Consultants		
Dr. Gordon Pask		12,000
Materials and Services		
Hardware Servicing	2,650	
EDP Supplies	4,850	
Electrical Supplies	7,150	
Mechanical Supplies	1,350	
Communications	2,100	
Office Supplies	3,800	
Printing Offset	1,400	
Xerox (B&W)	2,950	
Film and Video	2,950	
Subtotal		29,200
Publications		3,500
Equipment		30,000
Travel		
Domestic	5,500	
Foreign	2,400	
Subtotal		7,900
Miscellaneous		1,200
Overhead (68%)		85,862
Total		326,579

9.4 Explanation of Footnotes in the Budget

1. Equipment purchases, planned 1977-1978:

A thin film transistor display	$10,000
4K, 32-bit words, control store	9,000
1000 color monitor	6,000

2. Equipment purchases, planned 1978-1982.

With the exception of footnote 3, we are not enumerating specific purchase schedules: knowing the industry, that would be foolhardy. We propose to include in our annual report a specification of intentions that arise with the technologies. Our past experience has revealed that we cannot seriously plan equipment line items more than eighteen months in advance. Something always comes up that is a better product or better deal.

3. A $20,000 surge in the equipment line item appears in the fourth year. This reflects our best estimate of the availability of a large, flat display, akin to, if not, the Litton Industries or Control Data displays mentioned in subsection 5.4.5, Flat Displays. We would expect to start the fall of 1980 with a large pixel system, preferably where the pixels were memory as well as display elements.

4. Hourly staff refers usually to College Work Study Program (CWSP) matching funds. This figure is consequently multiplied five times in real dollars (i.e., $25,000 the first year).

5. There is no overhead on UROP stipends (subsection 7.2.4).

6. Publications appear as a line item in the third year only. This is discussed in section 5.5., Dissemination Program. Otherwise, publications are accounted for under "off set" and "Xerox" line items.

7. The foreign travel indicated is usually that of Dr. Pask. In this first year, seemingly backwards in the ratio of domestic to foreign, we include the IFIPS symposium mentioned in subsection 5.5.1, Publications Schedules and Plans.

8. This line item is for a visiting committee to review the work done by the midpoint of the proposal time period. This last footnote warrants extended mention, if not a subsection. Our current work started with a visiting committee reviewing our work in March 1973. The participants included: Ivan Sutherland, Herbert Simon, Alan Kay, and Gordon Pask, with whom we have since worked extensively. Additionally, the colleagues assembled (a second string, if you will) from other groups similar to ours, included: Valdimir Bazjanac (Berkeley), Steven Gregory (Utah), Patrick Purcell (Royal College of Art, London).

These visitors were accompanied by two NSF reviewers, Lou and Genevieve Katz.

The occasion served many purposes, not the least of which was the internal effect of rallying round a grand deadline to make things tick.

Since that occasion we have not re-enacted this scene, with some regret. In part we have not been able to coincide with NSF review (if that is proper); in part, we have not been able to assemble a similar cast of characters. We submit that it is an important item in our research agenda and can serve NSF well in reviewing our work at the midpoint of this five-year proposal -- but, we all know how quickly five years pass.

9. These funds would not cover the total publication of the document envisaged. They should instead be read as a subventure.

10.0 APPENDICES

Proposal to The National Science Foundation
Division of Mathematical and Computer Sciences
Computer Science Section
Intelligent Systems and Computer Systems Design

November 1976

From:
The Architecture Machine Group
Department of Architecture
Massachusetts Institute of Technology
Cambridge, Massachusetts