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COMPUTER CONTROLLED RESPONSIVE ENVIRONMENTS

A thesis submitted to the Graduate School of the
University of Wisconsin-Madison in partial fulfillment of
the requirements for the degree of Doctor of Philosophy

BY

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ABSTRACT

This thesis generalizes the concept of man-machine interaction to define an environmental tool which can be used for both scientific and aesthetic purposes. The computer perceives participants through a variety of sensors as they move around an environment and responds with synthesized sound and visual patterns. The first section describes several environments implemented by the author combining computer graphics, video projection and two way video communication. The second section generalizes from these samples to define an interactive art form and the aesthetic options it offers. It then describes the sensory hardware, audio synthesizers and visual displays as well as their interfacing to the computer. The final section describes applications of this environmental tool to psychology, psychiatry and education.

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INTRODUCTION

For most of the last century the distinction between Art and Science has been an easy one to maintain. Today these two disciplines are coming together with considerable force. This trend is part of a larger cultural implosion which is just beginning, the integration of all aspects of society by interconnected information, communication, and control systems. These networks and the computational power they bring will permeate our lives much as electricity does already. Their extremities will be cybernetic systems which sense our needs and respond with the services required. These systems will enter our offices, homes, and cars. We will live in responsive environments.

Definition

The author's work is concerned with expressing the essence of this responsive relationship, allowing people to experience in a limited and controlled way a playful representation of the coming fact. The vehicle for doing this is a computer controlled responsive environment presented within an aesthetic context, although its implications go beyond Art.

The environment senses the behavior of its occupants and responds in a way they can perceive. The result is a dialogue with the human participants expressing themselves through physical motion and the computer responding with light and sound. The environment can be completely controlled by a program or by a man who uses the computer to amplify his ability to interact with others. In either case, a programmer has anticipated the participants' possible reactions and provided different feedback relationships for each alternative. His program is a composition that can behave, respond, and learn on its own after it is completed. The design of such environments and the programs to control them represents a new medium of expression. The purpose of this paper is to define and explore it.

Since these environments separate technology from any single practical application, they can be thought of as tools for exploring the many ways man might interact with his machines. As we become more and more intimate with our technology, we must decide which relationships are most pleasing and judge technical alternatives by our aesthetics and values as well as their efficiency. Failure to do so will lead to further alienation of our culture from the tools that define it. To be comfortable with our tools we must be familiar with their implications, using them for own ends as well as to solve problems.

This dissertation is divided into three sections. The first section discusses the historical antecedents of the author's work and the three environments constructed at the University of Wisconsin: Glowflow, Metaplay, and Psychic Space. Glowflow was conceived as an effort to use technology to produce Art. Metaplay and Psychic Space depart from this concern. Their goals were to fully realize some of the implications of current responsive technology, to define an environmental medium based on it, and finally to compose experiences for the medium. In these environments, the emphasis was on involving the participants in a complex relationship rather than showing them a display which they could passively admire as Art. Both involved the interaction of computer graphics and video projection with a sensing system providing information about the state of the environment.

The second section defines the responsive medium. Its ramifications for the composer and audience are considered in the initial discussion. An outline of the hardware systems used for sensing and response follows. The software systems required for composing and operating the environments are then described in order to give a feel for the limits of what is possible with any given set of hardware. After discussing the separate ingredients it is possible to outline a general facility which can be realized with current technology and to project an ideal extension of that facility. The final step is to consider compositions which would be appropriate for such tools.

The third section deals with possible applications of responsive environments to other areas. There are a number of ways that responsiveness can be added to conventional Art forms such as Theater and Dance. The traditional framework of such media can be stretched to allow a true interaction between performer and audience. Also, since the responsive environment is really a fully generalized Skinner box there are obvious applications as a research and therapeutic tool in psychology, psychiatry, and education.

With any new technology, problems are created as well as solved; new options are discovered and others forgotten. The final chapter will identify some of these issues to put the rest of the discussion in perspective and to balance the author's optimism.

CHAPTER 1

ANTECEDENTS

1.1 Introduction

The purpose of this chapter is to trace the technical and aesthetic antecedents of the author's work. There have been concerns within each of these areas which suggest the appropriateness of responsive environments. These will be discussed separately according to the following outlines.

1.1.1 Technology

In technology, there are several trends which if extrapolated point directly to the author's interest. First, there is the need to represent ultrasensory data and to experience conceptual constructs. Second, communication systems are being called upon to allow full participation in events at a distance. An example would be the remote control of the lunar explorer by Russian scientists. Third, the need to preexperience dangerous or expensive situations has led to more complete simulation systems such as those used to train astronauts. Fourth, the next step in automation requires that machines be self-regulating, capable of anticipating the need for commands as well as following them. The first three trends suggest the liklihood of environmental displays involving all the senses while the fourth suggests that responsive technology will become an active, even intrusive, agent in our own environment.

1.1.2 Art

In Art the picture is less clear but it is still possible to identify very rough trends which augur the development of responsive environments as a means of expression. First, while much energy has been spent breaking away from old forms rather than defining new ones, each of these departures has isolated an aesthetic concern which becomes one factor in the environmental medium, e.g. light, motion, perception.. Second, the relationship of the artist to his work has been changing. He is likely to consider the process of being an artist more important than the actual objects that he creates. This trend provides the artist with the detachment required to allow audience participation to give his work its final form. Third, there is a confluence of artistic and scientific trends. Artists are using the scientists' tools, including the computer, for creating within their conventional frameworks. A much smaller number have realized the full implication of the new technology, the ability to create works that behave and respond. There are only a few works in this category and some of the most significant technological art has been the result of serious scientific efforts that inadvertently surpass those of the artists.

1.2 Trends in Technology

1.2.1 Conception Becomes Perception

The split between Art and Science widened as Science began to concern itself with phenomena beyond the human senses. For the last hundred years science has been absorbed with the ultra-fast, the ultra-small, the ultra-slow, the infrared, and ultraviolet, all invisible to the artist. Since he had no way of visualizing these phenomena, the scientist had to deal with them as conceptual abstractions to be experienced only by inference and calculation. Into this realm the artist could not follow. For a century, Art and Science have existed as separate cultures with neither understanding the other.

For the past few decades the process has been reversing; scientists have been increasingly concerned with perceptual representations of this ultra sensory data, the problem of mapping these new senses onto our original five. For instance, a new tool for medical diagnosis produces a color video image of the heat radiating from a patient's body by assigning each color to a particular temperature range.[1] Infected areas tend to be warmer than surrounding tissue and thus show up a different color. Scientists have also become increasingly more interested in creating perceptual representations of conceptual constructs using molecular models and three dimensional displays of mathematical function spaces.

So far, most of the effort has been directed at visualizing this information but it is likely that at some point it will become desirable to hear and feel it as well.

1.2.2 Communication or Coincidence

Another preoccupation of technological man has been telecommunication. Starting with Morse Code and moving through telephone and radio to television and color television, we have pursued the goal of transmitting the total experience of one place to another. With the exception of the first two these media are used as broadcast and dissemination systems that allow us to perceive events from afar. But more impressive are the remote control applications that permit a man to participate in distant events - to act from afar. For instance, the Air Force is working on a system which would allow a pilot to control a fighter plane from the ground.[2] Not only can the third of the planes' weight devoted to life support systems be eliminated, but the unmanned plane can perform maneuvers that would cause the pilot to black out if he were aboard. This desire to perceive and participate across distances will demand greater and greater bandwidth until all of our senses are involved.

Another aspect of communication which is seldom noticed[d] can be illustrated as follows. When one of my son's friends calls him on the phone, he consistently asks "Is Mikey here?". Adults usually think of communication as the transmission of information from one point to another because they are in full command of the real facts of geography. The child, on the other hand, knows that if he can talk to someone they must be in the same place. In other words, the concept of "place" is based upon the ability to communicate. The place created by the act of communication is not necessarily the same as that at either end of communication for there is information at each end which is not transmitted to the other. The place is defined by the information that is available at both ends simultaneously. We can expect a continuing desire to enrich that sense of place so that we not only interact verbally but will full gesture and touch as well.

1.2.3 Simulation

As thc tools of science become more expensive and the tasks to which they are set become more ambitious, we feel increasing pressure to minimize the risks of operator error and to anticipate these effects of bad design by preexperiencing the situation as fully as possible through simulation.

Most of these simulation systems are involved in research or military application. The flight simulators that are used to train pilots are very complete representations not only of the relevant information but of the whole experience.

Understanding the value of complete interactive representation of reality has led to the development cf 3D graphic systems which allow the user to visually explore a three dimensional design space.

McNoll at Bell Labs has used a stereoscopic graphic system to try to experience a four dimensional system by exploring its projections into three space.[3]

Ivan Sutherland at the University of Utah created stereoscopic apparatus which allows one to look around a simulated space by turning his head.[4] The motions of his head are sensed by the computer and the two visual displays altered to reflect the changes that would occur in his perception if he were actually in the space.

There is also a very sophisticated graphic system used by NASA to simulate moon landings. This program was adapted by Peter Kamnitzer to allow a person to perceptually enter a representation of a city, drive around it, and evaluate the design in a way that would otherwise be possible only in an existing city.[5] These last systems are essentially passive, the participant explores them, but they offer no novel input or experience, just a representation of some hypothetical physical space.

1.2.4 Closing the Loop

Another trend that is gathering momentum is the design of closed loop systems. Until now virtually all of our common technology has been open loop. We instruct it to do something and it does it. The only examples of closed loop systems that the layman encounters are the thermostat in his home and the automatic door at the grocery store. The minimal requirement for this type of system is a sensor which determines when its function should be performed. Not only can we expect to find automatic sensing systems in more and more of the technology we encounter, we already have traffic sensors that merge one flow of traffic with another, ultrasonic burglar alarms, and automated battlefields. We can anticipate devices which sense our presence in a room and regulate the sound and lighting accordingly. As these isolated devices become more sophisticated and are interconnected to form integrated systems and those systems given the ability to move and speak, we will be faced with the fact that, intelligent or not, the computer has entered our lives as an apparently living force. What we are now witnessing is a birth process, the birth of the artificial entity, an integrated perceiving, behaving system. Whether or not these entities will evince intelligence, is a completely separate issue, the artificial entity is inevitable. The lower forms are with us already.

1.2.5 Technology Summary

The examples just given indicate that there is a considerable amount of effort in the scientific world directed at richer and richer interactive systems. Whether the intent is communication or simulation there is the common goal of greater and greater bandwidth, of more and more real representations of reality or of hypothetical structures. The scientific interest presages a continuing interest on the part of our entire culture. Such pseudoexperience systems can be expected to become applied to education, psychology, and Art.

1.3 Aesthetic Background

1.3.1 Breaking Away from Old Forms -- Expanding Art

The aesthetic develpments preceding the author's work do not follow a linear trend. On the contrary, it is as if artists reached a discontinuity which they could not bridge either conceptually or economically. Starting with the Dada movement the traditional assumption that only painting and sculpture are Art has been challenged continually. Only after this point were the boundaries of Art diffuse enough to include ideas like response and environment. Since Dada, new ideas and new forms have been tried and discarded; or, if not discarded, filed away for future reference.

Each innovation resulted in a brief fad which expired when it was realized that it would be difficult to push beyond the original insight. Artists seem to have been more interested in a thorough exploration of the immediate possibilities than in laying the groundwork for new forms. Their lack of technical skills, and more importantly their lack of empathy with technology itself, have prevented them from seeing that the insights they already had contained the basis for a new tradition.

Many of these insights identify concerns which can be dealt with in responsive environments. Op Art including the works of Vasarely, Poons, and Riley gives the impression of motion to static paintings calling attention to the act of perception itself. Kinetic sculptors like Pol Bury, Jean Tinguely, and Alexander Calder introduced physical movement in their work rather than representing it. Thomas Wilfred's Lumia sculptures identified light itself as an aesthetic medium. More recently Kienholtz's Beanery introduced the idea of a crafted environment. Allan Kaprow's Happenings suggested that the audience should be more involved in the work. The responsive sculptures at the Cybernetic Serendipity show in London in 1968 offered another way that spectators might participate in Art.[6] Each of these concerns are quite clearly within the scope of the responsive environment and effectively dealt with by it.

1.3.2 Surrendering Control

1.3.2.1 Cage

As artists have discarded the limitations of traditional forms there have been some common elements making discreet appearances in the new ones. Most important is a new attitude among artists that they are no longer simply the creators of works of "Art". They are no longer to be judged exclusively by their command of a medium. In fact, in many cases, it is their willingness to forgo control completely that constitutes a contribution. The theme of surrendering control to influences within or beyond the artist has kept recurring in recent theorizing. It is motivated both by a desire to discover new kinds of order and to involve an audience.

The most earnest exponent of this kind of research is John Cage who has advocated a search for new sound patterns based upon the translation of all sorts of relationships drawn from other areas. While other use the word "randomness" when describing his method, Cage himself speaks of "unintended" sound.[7] He seems to say that he is bored with the sounds that he can make intentionally. If he can conceive the sound in his mind, knows how to realize it, and will not be surprised when he hears it, he has learned nothing. The whole exercise would be a waste of time. Therefore, he suggests that the musician become a more sensitive listener, surrendering to forms of order beyond those already explored. To find new forms, one must give up the kind of control which was learned from the old ones.

1.3.2.2 Happenings -- Kaprow

Cage's ideas of randomness and spontaneity influenced the invention of Happenings by Allan Kaprow.[8] There are several key aspects of a Happening which tend to legitimize the author's work aesthetically while in no way anticipating it. Most important, the Happening is theatre without an audience. Nothing is conceived with the passive spectator in mind. A very loose series of possibilities are planned and the participants are the ones who actually give it its final form. Here, as in Cage's work, it seems that the artist has surrendered immediate control, stepped back to a higher level, and given the actors and the audience a level of control heretofore unknown. Responsive environments also require the artist to accept reduced control, to think in terms of a structure of possibilities which leaves the final realization in the hands of each participant.

1.3.2.3 Process vs. Object Art

Another philosophical development in the Art community is the concept of process versus object Art. In the past, an artist was considered to be a person who created objects; these artifacts were the Art. Today we are at an awkward point in time. The objects being created by artists are so obviously not Art in the traditional sense that it is necessary to rationalize this fact, to apologize and explain that these sometimes poorly crafted works are mere clues to a grand and intelligent process of aesthetic exploration.

This behavior is appropriate because given new thinking and new tools it is premature to be concerned with producing finished works. The objective should be to experiment, explore the new domain, produce the tools to command it, and only then test the results against any criteria which may still seem relevant.

1.3.2.4 Lumia — Process Example

One artist whose work was done in this spirit is Thomas Wilfred.[9] He invented a method of composing with light which he called Lumia. Lumia is effected by projecting light through color transparencies and then bouncing it off curved reflective surfaces onto a screen. Both the transparencies and mirrors are slowly moved resulting in a long sequence of gradually transforming, wispy patterns of light. By changing the arrangement of the transparencies and reflectors a completely different composition can be displayed on the same equipment. Jean Tinguely, Alexander

Calder, and Pol Bury brought motion to object sculpture but not with the same generality as Wilfred. Each of their works were finished "pieces" representing a single set of possibilities whereas Wilfred's were instruments and tools for exploring a whole domain.

He identified a universe of possibilities and then concentrated on developing the tools needed to experiment within it, rather than producing works to be preserved as Art. He did produce such museum pieces only late in his life when he wanted to document his efforts. The pieces, however, are in no way his work, they rather suggest what his concerns were.

1.3.3 Art and Technology

The most recent trend of importance is the very gradual but increasingly steady involvement of the artist with technology. The display possibilities of video and computer graphics have been some of the attractions. Nam June Paik and Dan Sandin have developed video image processors which provide incredible imaging power. There is also a growing realization among artists that if they purport to speak for a technological culture they should not be ignorant of its tools.

1.3.3.1 Experiments in Art and Technology -- EAT

The last decade has seen an explicit effort to bring Art and Technology together on a large scale. This kind of work is typified by the EAT group which operates nation-wide but seems strongest today in Los Angeles. The organization recognizes that we have a unique situation, a world suddenly littered with unrealized possibilities created by new technology which have yet to be aesthetically exploited. Also unique is the fact that the aesthetic people, the artists, are almost deliberately without the intellectual tools needed to command the new technology. At the same time the technical people who understand the technology are without the aesthetic sense or the aesthetic confidence to express themselves through it. So the EAT credo is that, by bringing the artist together with the technologist, a creative fusion of the two cultures can occur.

Thus far, this has not happened. By relying on established artists, EAT demands that those involved have made reputations in conventional art forms. This seems to ensure that the resulting output will also be conventional for it is limited by imaginations that were trained in other fields. The fact that "Heart Beats Dust" was given first prize at the EAT show in New York in 1969 and the unimpressive show at the L.A. County Museum in 1971 indicates that so far EAT's achievements have been pedestrian.

1.3.3.2 Responsive Sculpture

With the new tools have come new concepts. Most important of these in relation to the author's work has been the awareness of the viewer manifested by responsive sculpture. Most of this work does not seem to have been conceived in a larger framework which would indicate the beginning of a long term trend, rather, it was done in the vein of gratuitously exploring another direction without any immediate plan to follow through. Most of these pieces involve only the most rudimentary knee-jerk responses to one aspect of the viewer's presence.

"Heart Beats Dust" displays the viewer's heartbeat by feeding it through a speaker covered with a membrane that is in turn covered with dust.[10] As the speaker vibrates the dust jumps a few inches into the air. Dante Leonelli's "Ball Wall" is an array of very large lighted globes which flashes through an orderly sequence of patterns until someone approaches it causing a more random progression.[11]

Also limited in their responses are the visually elegant sculptures of Tsai which consist of vertically mounted metal reeds set into periodic motion by a vibrator in the base. A strobe light, flashing at a slightly different frequency than the reeds' oscillations, creates the visual impression that the reeds are slowly undulating back and forth.

Among the most interesting of these works is the Searcher by Seawright which constantly scans its environment until it detects the presence of a person.[12] It then stops the scan and looks the person up and down, involving him in a very simple but satisfying relationship.

Another totally unknown work is even more interesting. William Wilke, a graduate student in Physics at the University of Wisconsin, builds small interactive sculptures that appear to be solid masses of rock crystals. A person communicates with the stone by gently waving his hands near the ends. Sequences of these small gestures which are sensed capacitively are understood by the stone as the basis for its instruction code. The stone responds to each code with a different pattern of lights. There is even one code which results in whirring sound and the slow exposure of a previously concealed compartment containing the batteries. The interaction is delightful and the craftsmanship superior.

1.3.3.3 Computer Art

In addition to EAT's efforts to merge Art and Technology in general there have also been concerted efforts to apply the computer to the generation of Art within conventional forms. Computer music may not necessarily sound like Beethoven, but the result is still a musical piece to be administered to a physically passive audience. The computer assists the development of content for an old form but does not lead to the invention of new ones. However, with one qualification the application of the computer to established arts is interesting to consider, particularly since some of the work has been done by technical people rather than bona fide artists.

1.3.3.3.1 Graphics

Computer graphics, currently limited to line drawings produced by plotters and CRT's, has provided the most widely disseminated examples of Computer Art. While there is no doubt that many of these works are interesting experiments, it is equally clear that static line images with no variation of thickness, intensity, or color constitute a very limited medium. Some recent results using a long exposure on a CRT have produced photographs of smoothly surfaced solids instead of line drawings; however, these figures are also quite simple. Unfortunately, with existing equipment any system that relies on the computer as its sole source of complexity is certain to produce simple results. It would seem more appropriate to make more use of complex inputs from a human operator than to rely solely on computation.

1.3.3.3.2 Film

Computer films, while they suffer from some of the same limitations as the graphics, tend to be more satisfying aesthetically. Ken Knowlton at Bell Labs has produced a language called Beflix which has been used by Stan Vanderbeek and others to produce movies. While the aesthetic credit for these films goes to the artists, the mosaic format immediately identifies the films as deriving from the universe defined by Knowlton.

John Whitney's movies such as "Permutations," seem to be the result of very sensitive aesthetic interaction with what appears to be a fairly simple programming system. The images are limited but their motions very carefully orchestrated. They represent the beginning of an art form based on sequences of abstract visual patterns analogous to the abstract sound sequences of music.

The most impressive film from a programming point of view is "Cybernetick" by John Stehura. This film represents a virtuoso programming effort with far more complex images and transformations than the others. Stehura was also working on an extensive language for defining complex images and sequences. To the author's knowledge, this system has not yet been implemented.

An entirely different approach to the computer is taken by Bob White, a local filmmaker. White uses the computer to facilitate certain techniques in filming real-world images as well as using computer images. In his film "Cadmium Red," he used the computer to provide a record of his responses to a piece of music, Purple Haze. The computer output, which was a record of his responses and the frame numbers at which they could occur if the music were the sound track of a film, was then used to direct the shooting of real images, frame by frame, so they would be synched with the music as he desired.

1.3.3.3.3 Computer Music

In using the machine to analyze, compose, and perform, musicians have perhaps made the most extensive use of the computer. There are a number of systems for designing sounds and for structuring them in sequences for creating pieces. Bell Labs created the Music-V system for specifying sounds.[13] The Groove system also at Bell Labs permits the creating, editing, filing, and playback of synthesized sounds in real-time.[14] This system is used to control conventional synthesizer hardware (Voltage Controlled Oscillators and Voltage Controlled Amplifiers) by means of DAC's (Digital to Analogue Converters).

Another more general experimental system is being developed by Joe Pavlat, an undergraduate at the University of Wisconsin. His system is based on Fourier synthesis of any sound as a sum of its harmonics. This system is obviously not real-time but since much of the computation could be done in parallel, it could be made so if special hardware were built.

1.3.3.3.4 Batch Processing Model

With the possible exception of Groove, all the work in the three main areas of Computer Art seems to be based upon a batch processing rather than an interactive model of programming. In all cases, the work is specified, programmed and the output then accepted as the composition. However, the computer could allow the artist to explore a line of development, intervene at every step, judge the outcome, and then use it or discard it. The computer should increase the artist's ability to experiment so that his final compositions are based upon a much richer experience with the sounds he selects. The author has contributed to the general design of a system conceived in this spirit by Bert Levy, a composer at Suny, Albany.

This system will not automate the entire act of composing but rather provide real-time manipulations of compositional data. The input starts with the specification of aesthetically interesting musical ideas. The composer then identifies the salient features of these ideas, the global design of the piece, and the kinds of manipulations which are appropriate to the muscial idea. As the machine processes, he stays in the loop to judge the implications of his original conception. He can then save or discard the result of any transformation or revise any part of his original design statement. He can iterate through the process, interacting with every level of decision, if he chooses, building larger and larger structures until he is satisfied that the computer can help him no further. The output may or may not be a finished piece.

Most likely the composer will want to add the final refinements himself. In such a system it is the division of labor that is important; the computer is being used to compute, the composer to explore and select.

The author's preferred approach to compositional systems is based upon the work of one of his past students, Fred Ostapik. He designed a simple system for creating graphics. When a picture was generated, the programmer critiqued it according to any of a considerable number of parameters. Upon digesting the critique, the program generated another picture which reflected the criticism. This process was iterated, the program adapting to the taste of the artist until he was satisfied or exasperated. The important feature of this approach is that the composition is treated as a behaving entity which can be made to explore its possibilities and trained to seek those that please the user.

1.3.3.4 Computer Controlled Responsive Art

Finally, we will consider the use of the computer to create a new art form; i.e., one that is not possible without it. One essential aspect of the computer is that it can assimilate information and make decisions in real-time. The possibility of real-time art was so remote in the past that no one even thought to desire it. While there are only a few such works, they point in a direction of a major thrust in both Technology and Art. These works are much like the author's in that they animate technology, they give it senses to perceive humanity and rules of behavior by which to respond. The artist externalizes, not simply the way he perceives, but also the way he responds. He anticipates the way people will act and defines the ways his work should respond. He designs a system which will interact with others for him in a way his physical and mental limitations would not permit. The result is a dialogue between his work and the spectator.

1.3.3.4.1 PULSA

One of the first works of this sort that the author is aware of was that of the PULSA group at Yale which designed both indoor and outdoor environments, using strobes programmed to respond to the movement of people through the space. Sensing at the museam of Modern Art was apparently done by using photocells facing a TV monitor to detect changes in a video image of the environment.[17]

1.3.3.4.2 Cybernetic Tower

The most monumental work is a 1000' high light sculpture designed by Nicholas Schoffer being built in Paris.[18] The Cybernetic Tower will have hundreds of moving light beams whose patterns will reflect the vital signs of the City: the weather, the stock market, traffic flow, etc. Since the tower is conceived as a gigantic display rather than a responding entity, the public will not have an conscious ability to affect its behavior except in mass. The limitation is political; the tower could be provided with senses to focus directly on small areas and individuals.

1.3.3.4.3 Seek

The SOFTWARE Show in the Jewish Museum in New York in 1970 contained what claimed to be the first significant work of Computer Art.[19] It is important to ignore the possibly offensive works "first", "significant", and "Art" in the description in order to assess its truth. SEEK, the work referred to, was conceived by a group in the Architecture School of MIT. It consisted of an existing piece of extremely sophisticated technology, i.e. a system whereby a computer could build simple structures out of blocks within a small environment.

The space was inhabited by a number of gerbils, small mice-like rodents, who were expected to keep knocking down the computer's structures. The computer was expected to be constantly mending its walls in response to these agents of entropy. Unfortunately, according to Jack Brunham, the guest curator who organized the show, the piece had not been tested on the gerbils which apparently kept close to the boundaries of the space and so had only minimal interaction with the blocks which were in the center. At least this system did provide for sophisticated behavior in response to real world inputs.

1.3.3.4.4 Senster

The most impressive sculpture to date is a piece called SENSTER done by Edward Ihnatowitz.[20] This is a large animal-like sculpture with hydraulically articulated limbs and multiple acoustic sensors which give it the ability to select a single sound source among many or focus on certain sound levels or pitches. It has a sophisticated and variable behavior repertoire and is reputed to be capable of learning in the sense that learning programs can be used to modify its behavior. It is not clear whether this capability is implemented or was precluded by financial and time constraints. It is difficult to judge how satisfying interaction with this creature can be for it seems to be physically separated from the viewers, limiting its behavior to that of an animal in the zoo. Whether the situation allows for more than orienting its sensors and body toward sources of sound can not be determined from the literature. This thought makes one reflect whether a physical entity does in fact provide the richest range of possibilities for interaction as one might initially suspect. The aesthetic issues of determining the richest medium for feedback relationships will be considered further in later chapters.

1.4 Conclusion

As technology becomes cheaper and easier to use, the artist will have access to it. Also, as we find ourselves operating more and more in an environment of our own rather than Nature's shaping, we will realize that the design of our environment and our interaction with it is an aesthetic problem as much as an engineering one. However, the aesthetic input cannot come from aesthetic specialists any more than it can come from technical specialists. The design of interactive environments represents a new focus, the interaction, and so will train its own people.

CHAPTER 2

GLOWFLOW

2.1 Background

Glowflow, shown in the Union Gallery in April 1969, was the first computer controlled environment at the University of Wisconsin. It was conceived by Jerry Erdman, Richard Venezsky, and Dan Sandin. The author joined the project immediately after the initial conception. The show was supported by grants from the National Science Foundation, Ford Foundation, and the loan of a PDP-12 computer from Digital Equipment Corporation.

2.2 Conception

2.2.1 General

The project was conceived in an atmosphere of encounter between art and technology. The conception provided for an aesthetic light-sound environment controlled by computer, with some provision for responding to the people in it. While the original plan was a group effort, the visual and musical designs developed independently. Jerry Erdman's visual conception was to provide a darkened room where the display would define perceived space only partly faithful to the physical space used. Changes in the display were indirectly contingent upon the actions of the participants. It was felt that immediate responses would quickly become trivial and boring, serving only to reinforce noise in what was intended to be a quiet, contemplative environment.

2.2.2 Environment

The physical environment was an empty rectangular room constructed within the Union Gallery (figure 2-1). The display consisted of a suspension of phosphorescent particles in water, pumped through four 1/2 inch transparent tubes around the room. Each tube contained a different color pigment. Since the room was dark the lighted tubes provided the only visual reference, defining the visual space. The tubes were arranged on the walls in such a way as to distort one's perception of the room when they were lighted (figure 2-2). Because of this arrangement the rectangular room appeared to be wider in the

Gallery floorplan for Glowflow

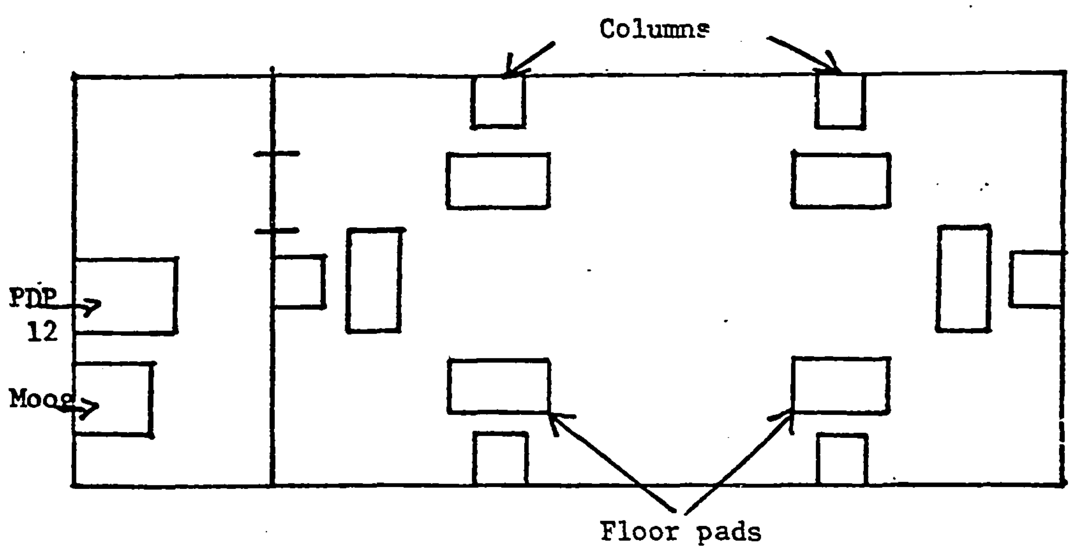
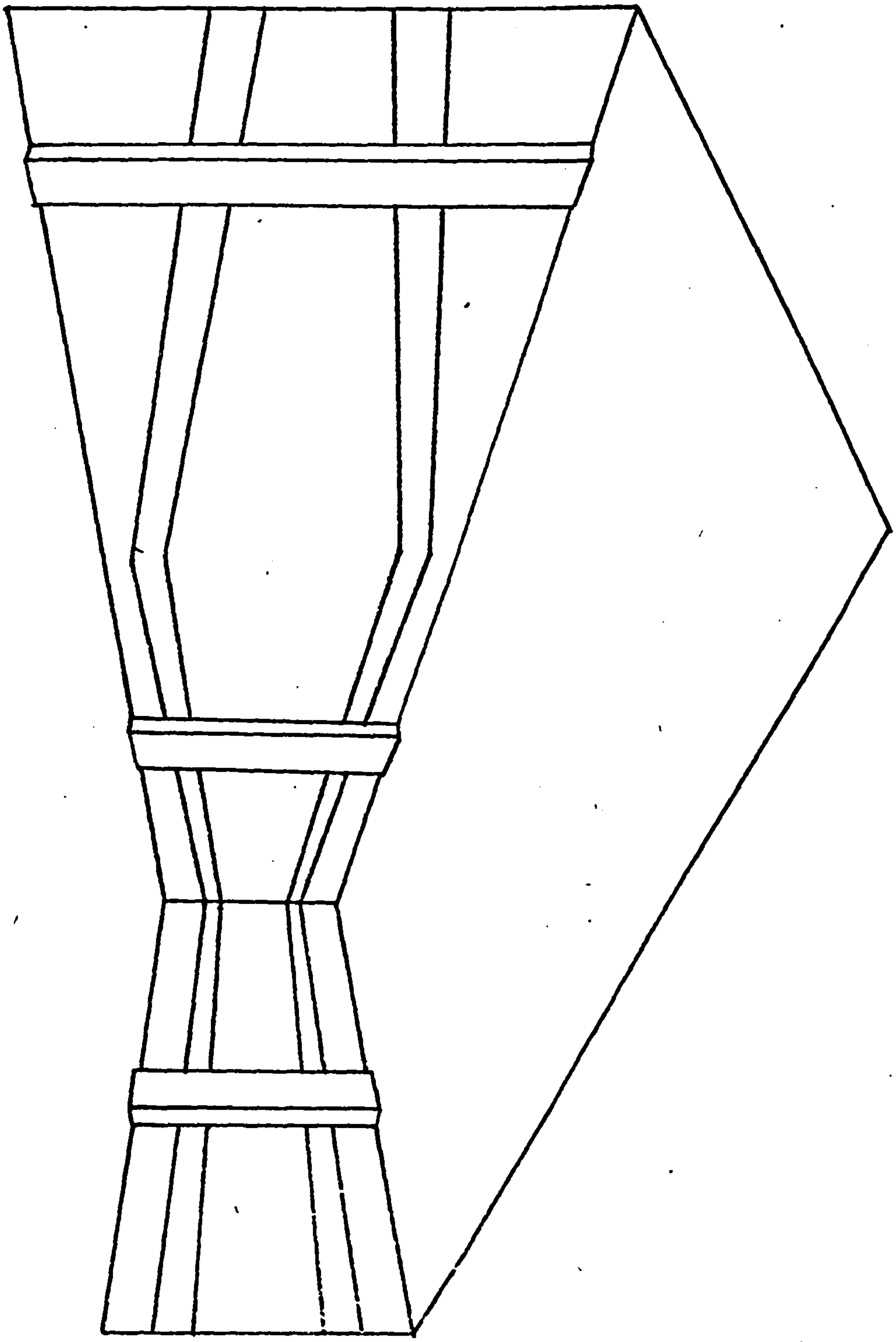


fig. 2-1



Glowflow tubes on gallery wall fig. 2-2

center than at the ends. Also, because the room was otherwise dark, the bottom tube was assumed to be level with the floor. Thus, one experienced an illusion of going downhill with respect to the "floor" as one walked toward either end of the room.

The tubes were run through columns along the walls. It was in these columns that the phosphors were excited and from which the glowing would flow. Each column contained four lights, one for each tube passing through it. The tubes were looped around the bulbs to gain maximum exposure to the light (figure 2-3). When a light was turned on, it could not be seen because the column was sealed; however, the substance flowing through the corresponding tube would start to glow as it came out of the column, glowing less and less as it moved along the wall until it finally decayed approximately twenty feet away.

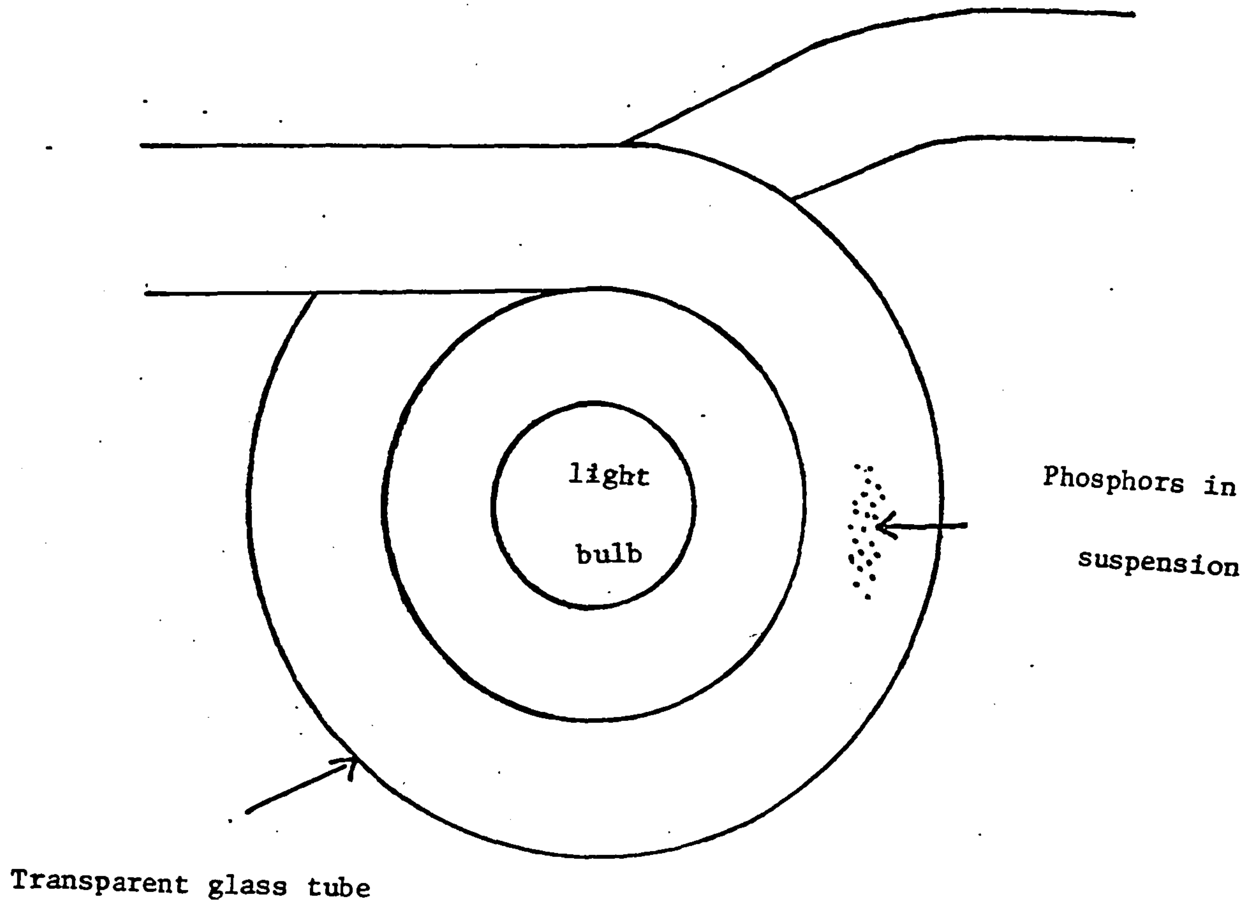
There were six columns, two along each of the side walls and one at each end. With four lights per column, there were a total of 24 lights which could be turned on or off in any combination by the computer. A glowing line could be set in motion along any tube from any column. Thus, it was possible to light all of the lines from one column or all of the lights along a single line around the room or a random pattern of lights.

2.2.3 Electronics

The environment was controlled by the PDP-12 through an interface built for the show by the Space Astronomy Laboratory. The interface consisted of thr^e boxes: one for speakers, another for the Moog

fig. 2-3

System for activating phosphors



patching, and a third for the lights. In each box there were a number of double latching relays: 10 for the speakers, 32 for the Moog, and 29 controlling AC lines for the lights. The interface was controlled by six bits from the computer. The high order bit was used for stepping through the six states of the interface. The first three states corresponded to the three boxes. When in one of these states, the five low order bits were used to indicate which of the relays in that box should be set. Ten milliseconds were required for the mechanical relays to latch. The fourth, fifth, and sixth states also corresponded to the three boxes. If the interface stayed in one of these states for more than ten milliseconds, all of the relays in the corresponding box were cleared. This was the only way that any relay could be switched off. So, if ten relays were set in a box and one needed to be turned off, the entire box was cleared and then the nine relays had to be restored. A tenth of a second would elapse from the time all of the relays were turned off to the time the last relay was restored. This kind of delay was not a problem with incandescent bulbs but was noticeable with sounds. The state of the interface was communicated to the PDP-12 by an analogue voltage.

The PDP-12 controlled a small Moog synthesizer via the interface. The Moog sounds were fed through amplifiers to the speaker in each of the columns. It was possible to feed sound through any combination of the six speakers. Thus, it was possible to make sounds rotate around the room or go from one wall to the other. However, the transition from one set of speakers to another was not continuous, requiring some time delay to avoid a popping sound.

The only sensing devices were pressure sensitive pads in front of each of the six columns. In each of these pads was a switch which could be sensed by the computer. The pads sensed the presence of a person standing on them as distinct from the impact of a person's step. The programming could have compensated for this had immediate responses been desired. Microphones were discarded as sensors because responding to noise would encourage more noise.

2.3 Experience

2.3.1 Response

The room was kept dark. Between fifteen and twenty people were in the room at any one time, with new people being allowed in as others left. There tended to be several stages in each person's experience in the environment. First there was an initial disorientation due to the darkness. During this period people would stay near the entrance. Then as their eyes grew accustomed to the low light level they would explore the room, discovering the illusory nature of the perceived space. Later they might sit or lie down on the floor interacting with other people or in quiet contemplation. As long as there was some turnover, there was no pressure on people to leave the room.

There were rather amazing reactions to the environment. Communities would form among strangers. Games, clapping, and chanting would arise spontaneously. The room would seem to have moods being sometimes deathly silent, sometimes raucous and boistrous. Individuals would invent roles for themselves. One girl stood by the entrance and kissed each man coming in while he was still disoriented by the darkness. Others would act as guides explaining what phosphors were and what the computer was doing. In many ways the people in the room seemed primitive, exploring an environment they did not understand, trying to fit it into what they knew and expected. Since the publicity mentioned the responsiveness, many were prepared to experience it and would leave convinced that the room had responded to them in ways that it simply had not. The birth of such superstitions and myths were continually observed in a sophisticated university public.

2.3.2 Responsiveness

As had been mentioned, the artists' attitude toward response was ambivalent. Responsive relationships were seen as conceptually interesting to the artists. It was important that the environment respond but not that the audience be aware of it. The idea of direct response to movement and voices was discarded. It was feared that if immediate responses were provided the participants would become excited and think only of eliciting more responses. This active involvement would conflict with the quieter mood established by the softly glowing walls. The power of responsiveness was recognized but then avoided as not in keeping with the predominantly visual conception.

The environment responded to the people in the room in various ways. For instance, a sound might rotate around the room if a person was on a certain pad, or the pattern of lights might change. There was little sensation of interaction for several reasons. First, there were often delays programmed between action and response. Consequently, the computer might respond to a person a minute after he sat down on a pad. Of course, he would not be aware of it because he had not done anything for the last minute. Second, the large number of people in the room meant that any response might have been elicited by someone else's action. Finally, the medium of glowing and flowing is slow to respond; it requires seconds for a line to appear and decay. Thus, if a person does cause a response he is unable to repeat it immediately to verify that he caused it. With such intermittent responsiveness it is impossible to establish an intimate relation between action and display. So while Glowflow was quite successful visually it was precisely the visual conception which limited the responsiveness.

2.3.3 Music

The music in Glowflow was never heard in its entirety due to hardware difficulties. The Moog was connected to the PDP-12 allowing a number of very simple sounds. However, the program planned by Bert Levy and implemented by the author used a stochastic model for the generation of the music. Provisions for a very rudimentary responsive capability were added by the author. The program actually used provided only for the setting of some thirty different patches yielding simple sounds which could then be directed to the various speakers.

The model planned was based on statistical variation around a compositional unit called a major cycle. The major cycle was divided into a number of smaller time units called minor cycles about one second in duration and weighted according to the likelihood of sound during that period. Similarly, each minor cycle was further divided into a given number of smaller time increments, each of which was again assigned a weight for the probability of a change in the analogue control voltage from the computer to the Moog (figure 2-4). If there were to be attacks during a given minor cycle, the timbre routine went through a network of weighted decisions which chose the waveform and type of modulation (figure 2-5). One of three decay rates was also selected. These decays were the only envelopes available. Choices of analogue voltages were based on a probability distribution associated with the previous value. Due to the memory limitations of the PDP-12 only eight discrete voltage levels were used (figure 2-6). The events of a given minor cycle were repeated from one to five times depending on another distribution called the redundancy vector. The score for one of the compositions is included as Figure 2-4, 2-5, and 2-6.

The responsiveness added to this program varied either the pitch range being used or forced an attack when a person was on one of the mats. Also it was possible to make other more subtle changes such as adding or deleting white noise or reverb. The program while primitive presented an interesting first step for responsive sound, a new discipline in itself.

2.4 Lessons

The experience of Glowflow led the author to several conclusions:

1. Response is an important medium by itself.

Rhythmic Events

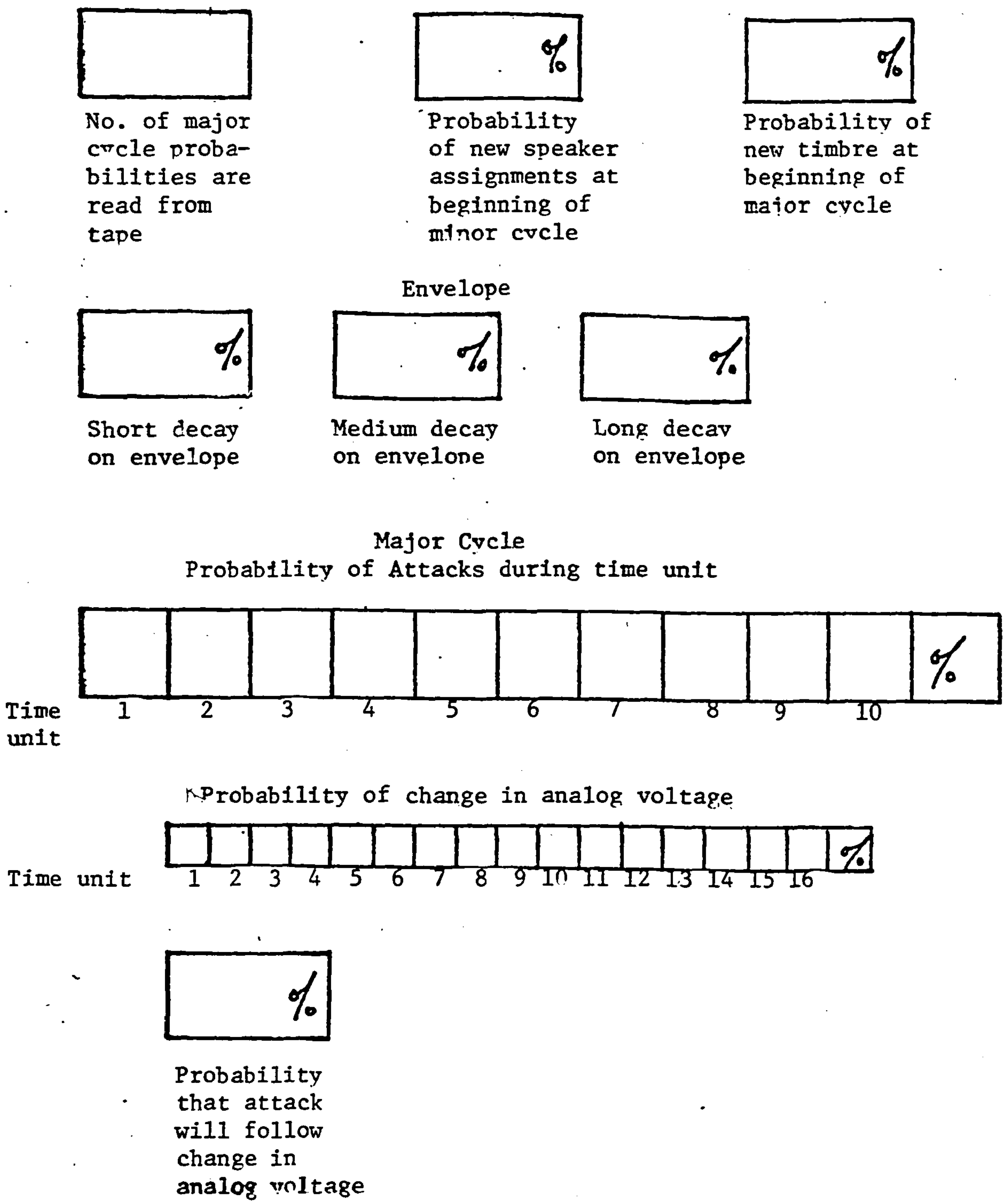


fig. 2-4

Timbre

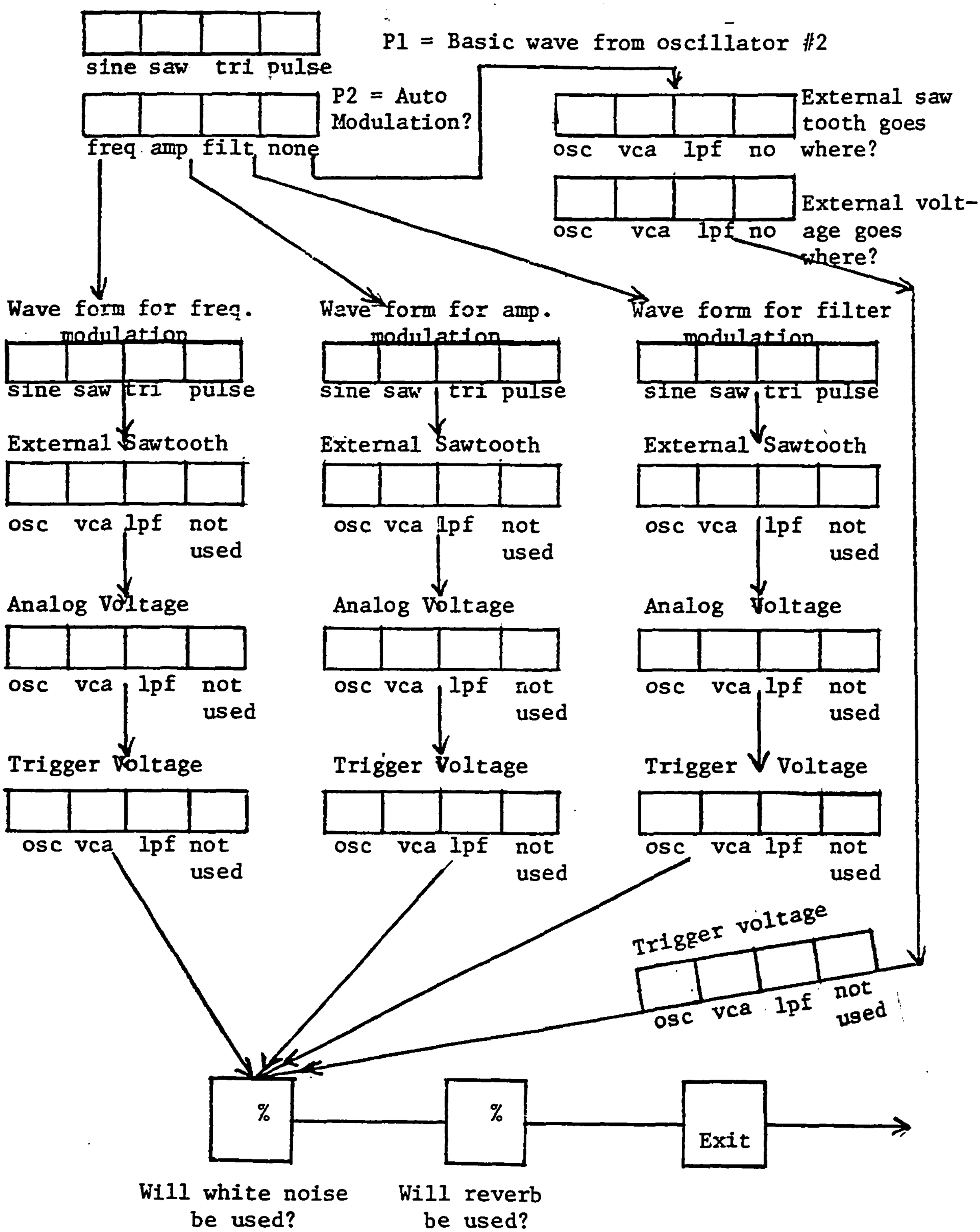
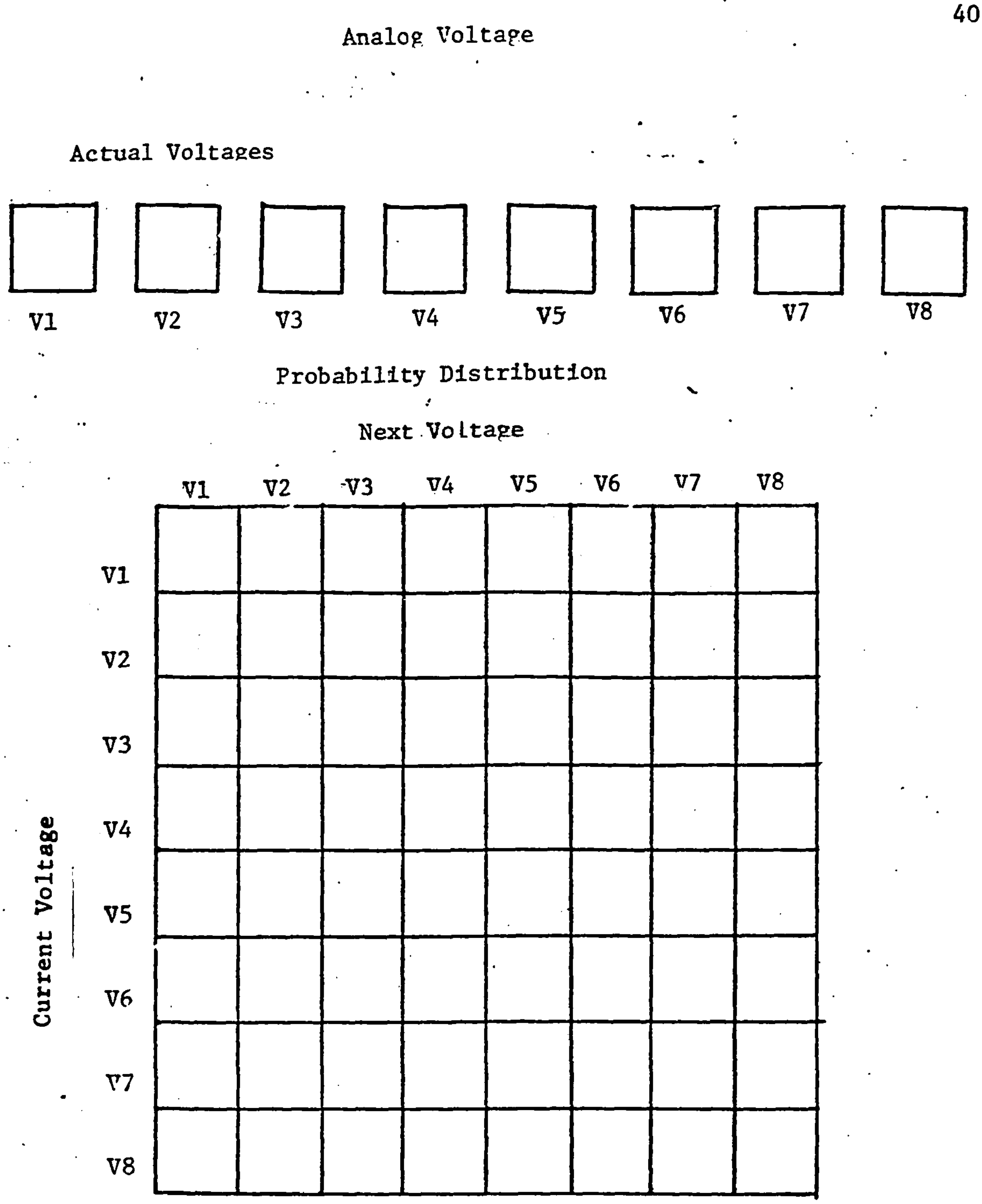


fig. 2-5



Probability of changing from Vi-Vj

fig. 2-6

2. The original conception should provide abundant opportunity for response.

3. Darkness is an important aspect of the environment, but the period of dark adaptation is not useful aesthetically and can be accomplished beforehand in an antechamber.

4. Sensing must be for change of position and not presence, and must provide many more than the six inputs of Glowflow.

5. In order to focus on man-environment interactions rather than man-to-man interactions it would be best to limit the environment to one person at a time.

6. The original conception must provide for the integration of the light and sound displays. (Otherwise, the result is a competent visual conception and a competent musical conception with no apparent justification for the two existing in the same space).

CHAPTER 3

METAPLAY

3.1 Background

Metaplay was presented in the Union Gallery during the month of May 1970. It was conceived and directed by the author and implemented with the help of his students. Thousands of man hours of occasional labor were recruited among the students at large as they wandered through the Union. The show was supported by the National Science Foundation, the Computer Science Department, and the Graduate School. Digital Equipment Corporation loaned a PDP-12 and the Electrical Engineering Department loaned a TR-20 analogue computer.

3.2 Conception

3.2.1 General

The concerns of Metaplay were a radical departure from Glowflow. The criteria of Art and Beauty and the subtle handling of responsiveness were discarded. The focus was on the interaction between the participants and the environment. A long-term commitment was made to individualizing the interaction so that people's experiences would differ. This goal required that a number of independent hardware-software systems be implemented. In addition, this environment was designed with the awareness that the complexity of the equipment made intermittent partial failures inevitable; therefore, whatever equipment failed some sort of show was always possible with what remained.

3.2.2 Interaction

Two approaches were taken to the interaction. In the first the computer was used to facilitate a unique real-time relationship between the artist and the participant. The live video image of the participant and a computer graphic image drawn by the artist were superimposed and rear-projected on the screen at the end of the space. The viewer and artist both responded to what they saw on the screen. In the second approach a series of simple feedback relationships between the viewer and the computer were under automatic computer control. As the viewer moved around the environment the computer responded with electronic sound and projected graphic images. Since the two approaches were quite different, they will be described in separate sections below.

3.2.3 Environment

The physical environment was an empty, squarish, dark room with one wall dominated by an 8' x 10' rear-view projection screen (figure 3-1). The remaining walls were painted with phosphorescent pigments. A large sheet of black polyethylene on the floor concealed 800 pressure sensitive switches.

Metaplay

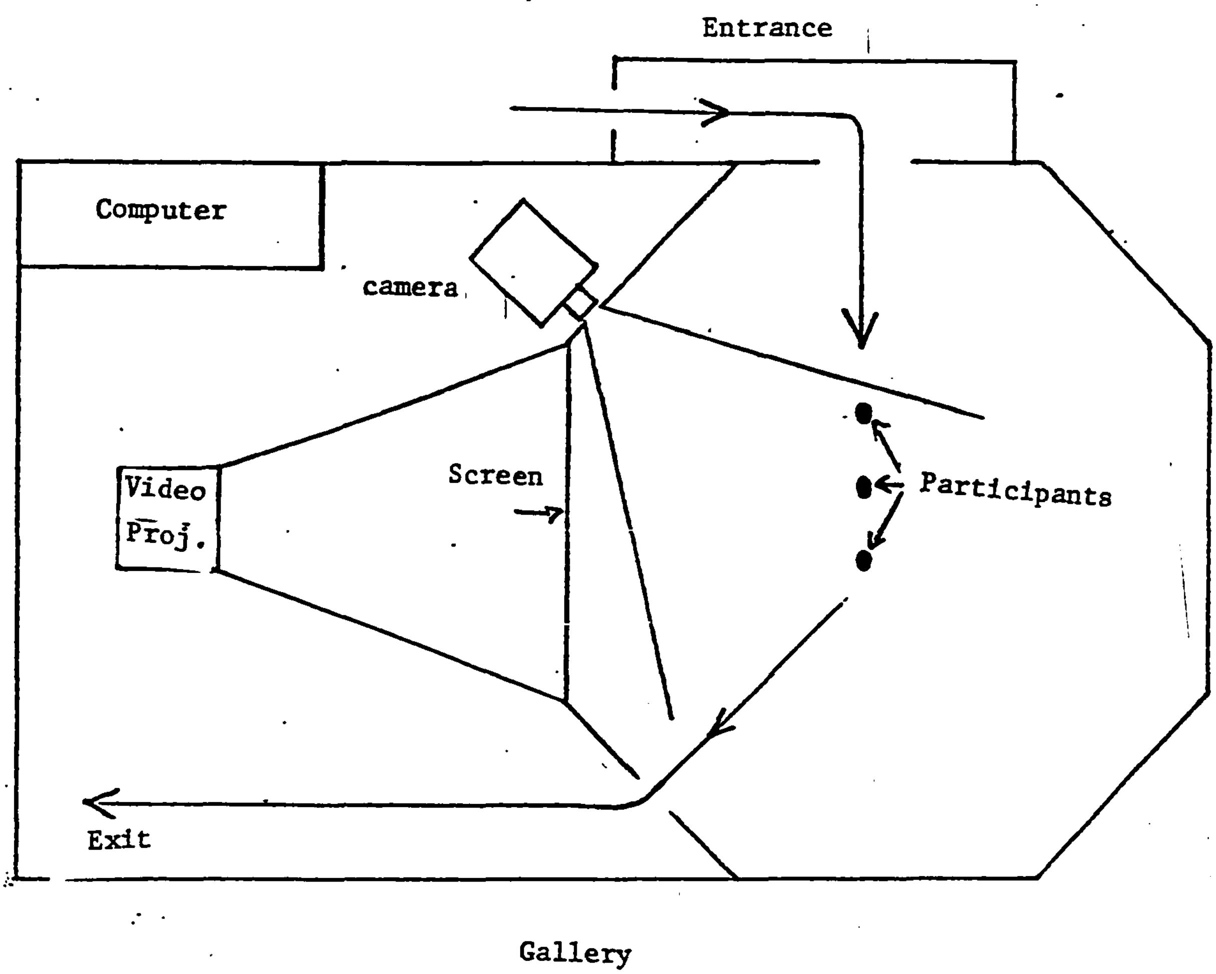


fig. 3-1

3.2.4 Display

To express the interactive relationships, a commanding real-time display was needed. The most versatile existing real-time displays are the graphic display computer and closed circuit video. The problem with both of these media is one of scale; the standard 25" monitor is too small to be an environmental display because we are conditioned to sit and watch rather than interact with it physically. The solution was to convert the computer image to video and rear project it on an 8' x 10' screen that dominated one wall of the environment using a video projector. The two kinds of images could be shown separately or superimposed. The result was an effective but unbeautiful display. The marriage of computer and video images was quite important and will be considered further in the chapters on Sensing and Displays.

3.3 Approach #1 -- Facilitated Interaction -- Live Drawing

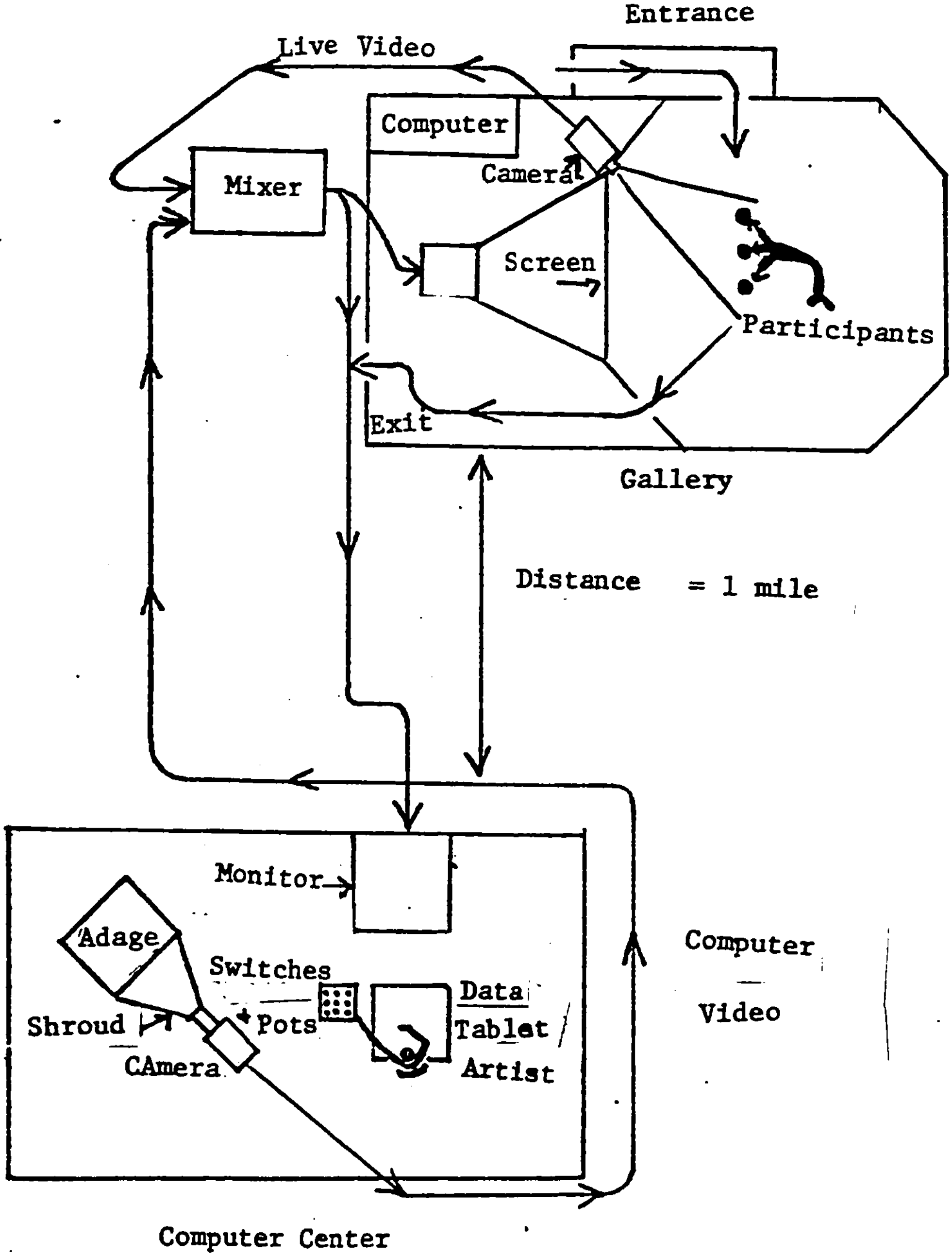
3.3.1 Hardware

The following description of the data links is a little confusing and will be represented logically below and visually by Figure 3-2. The image communications consisted of:

1. An analogue data tablet whereby the artist could draw or or write on the computer screen. The person doing the drawing was not necessarily an artist but the term is more convenient than "drawer" or "interactor".

2. A video camera pointed at the computer graphic display screen.

3. Television cable transmission of the video computer image from the Computer Center to the gallery.



Metaplay Communications

fig. 3-2

4. A video camera pointed into the gallery, picking up the live image of the people in the room.

5. The mixing of the two video signals so that the computer image was overlayed with the live image.

6. Rear-view TV projection of the composite image 8' x 10' into the gallery.

7. Transmission of the composite image back to the Computer Center.

8. Display of the composite image on a video monitor, providing feedback for the artist's control of the graphics.

The result was that the artist could see the people in the room and draw lines on their images as they watched themselves on the rear-view projection screen. He received the same visual feedback they did, since he watched the monitor instead of the computer screen. He also had voice communication with the cameraman in the gallery.

3.3.2 Control

The artist in the Computer Center could draw on the Adage screen by moving the pen on the Analogue Data Tablet. By using function switches, potentiometers, and the teletype keyboard he could rapidly modify the pictures he generated or alter the mode of drawing itself. In addition to simple drawing:

1. A small shimmering symbol was used to point at people in the image.

2. The picture could be moved about the screen.

3. The size of the generated image could be controlled.

4. The picture could be repeated up to ten times on the screen displaced by variable X, Y, and size increments.

5. A tail of a fixed number of line segments could be drawn. As a new segement was added at one end, the one at the other was removed.

6. The figure could be rotated in 3-space under control of the pen. This transformation was not true rotation but the visual effect was the same.

7. A simple set of transformations under potentiometer control yielded apparent animation of people's outlines.

8. Previously defined images could be recalled.

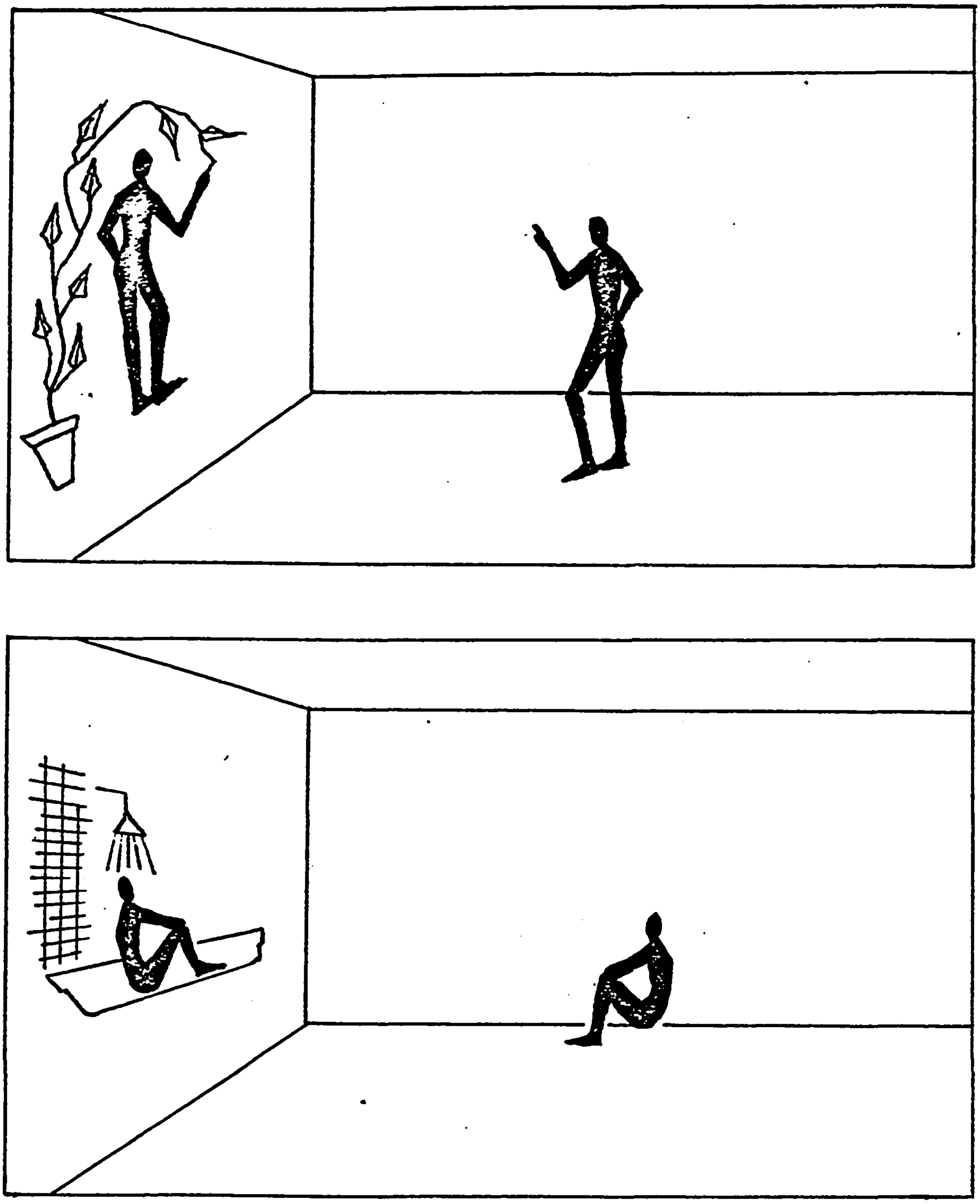
9. Existing images could be exploded.

While it might seem that the drawing could be done without a computer, the ability to rapidly erase, recall, and transform images required considerable processing and created a far more powerful means of expression than a pencil and paper ever could alone.

3.3.3 Interaction

3.3.3.1 Drawing

These facilities provided a rich repertoire for an odd kind of dialogue. Many approaches were tried with new ideas cropping up throughout the duration of the show. Using the drawing tools described above the artist could draw pictures on the participants' images (Figure 3-3). For instance, he could draw a bathtub or a boat around them so they would appear to be in it. He could draw a bed and have the TV camera tilted so a standing couple would appear to be lying on it. He could communicate directly by writing words. Or he could try to induce them to play a game like Tic-Tac-Toe. He could play with the act of drawing, starting to draw one kind of picture only to have it transformed into another by interpolation or some other techniques.



Metaplay Drawing

fig. 3-3

3.3.3.2 Live Graffiti

One interaction derived from the artist's ability to draw on the image of the audience. He could add the graffiti-like features such as moustaches and breasts. After drawing an outline around a person he could animate it in such a way that it appeared to dance to the music in the gallery. The drawing would proceed with the artist trying one idea after another in his effort to involve a particular participant. Failing with one person he would instruct the cameraman in the gallery to focus on a more playful looking person. Thus the artist had control not only of the drawing but of the aiming and zooming of the camera.

3.3.3 Participant Drawing

One of the most interesting relationships came from our desire to have a way for the people in the environment to draw. The wand which was to have accomplished this electronically was not completed. The solution discovered accidently was perhaps preferable. One of the first days of the show we were trying to draw on someone's hand. He did not understand what was happening and moved his hand. I erased what I had so far and started over where his hand had moved. This became a game with him moving his hand just before I finished my drawing. The game degenerated to the point where I was simply tracking the image of his hand with the computer line. So by moving his hand he could draw on the screen before him. This idea became the basis for many interactions.

We tried to preserve the pleasure of our original discovery for each of the people we wanted to involve in this way. After we had played some of the graffiti games with each group, we would focus on a single person. Then we would busily draw around the image of his hand. The reaction was usually blank bewilderment. After a minute or so the by this time self-conscious person would make a nervous gesture like scratching his nose. Another minute would pass with his hand frozen to his nose, while his mind pondered. Then a tentative movement of the hand. The line followed. It worked! An he was off, trying to draw. Then the others would want to play. By now using his finger he would pass the line to someone else's finger and they would carry it to the next. Literally hundreds of interactive vignettes developed within this rigidly narrow communication channel.

Drawing by this method was rather a rough process. Pictures of any but the simplest shapes were unattainable. This was mainly because of the difficulty of tracking the person's finger as he moved it. If he moved slowly there was a chance that he could really draw something -- otherwise none. The analogue data tablet used to input the drawing to the computer was also a low resolution device, further frustrating real drawing. But neither the artist nor the audience were ever concerned by the limitations of the drawings. What was exciting was that we were interacting in this peculiar way through a video-human-computer-video-communication link spanning a mile.

3.3.3.4 Typical Experience

The sequence of events started with a group of six to ten people entering the darkened environment. The the lights were brought up and their projected video image became visible. The typical audience reaction at this point was a surprise to the author. Often, faced by the large screen where the only active element was their own image, they would sit down and watch themselves. We discovered that large screen video projection was unheard of for many of the participants, and therefore allowed at least a minute for them just to appreciate it. After their initial awe was overcome, one of the interactions just described would ensue. These were terminated by the lights dimming and the artist writing "Goodbye" or the equivalent.

3.3.4 Possible Future Extensions

The most effective addition that could be made to this part of the show would be to darken the room and use an infrared television camera to pick up the image of the people in the environment. This would make the surprise of the projection even greater, for while most technically sophisticated people are intellectually aware that sniperscopes exist, even they have had almost no real experience with such devices.

Further extensions would be to give the people in the dark room a wand with a light at the tip, which could then be tracked by a television camera. The camera signal would be fed into a monitor modified so the horizontal and vertical deflection voltages would be sampled when the dot from the wand was being drawn by the electron beam. These voltages would be an accurate indication of the coordinates of the wand in the television picture. Ultimately computer pattern recognition of the video image should permit it to identify and track the person's finger automatically.

Also, the repertoire of programmed capabilites can be greatly expanded. The person's video outline can be sensed electronically and fed into the computers. The computer can then generate images around him, bounce objects off of him and even animate organisms which can eat his image bit by bit. More transformations of one image into another can be added. A number of other ways that live people images can be combined with computer images will be described further in the chapter on Sensing and Displays.

3.4 Approach #2 -- Computer Controlled Responsive Environment

3.4.1 General

The second approach was to program automatic responses by the computer. The reactions of the artist in the first approach were replaced by a program that monitored the participants' behavior and defined a composed series of feedback relationships using a Moog synthesizer and the Adage Graphic Display Computer. The two kinds of feedback will be described separately below.

3.4.2 Hardware

3.4.2.1 Floor

Both the graphic and music responses were based on the positions of people in the room as determined by the floor sensing array. This array consisted of 768 pressure sensitive switches arranged in a 24 x 32 grid. The large number of sensors compared to the six used on Glowflow reflects the feeling that the computer must know as much as possible about the participants' location and behavior.

The switches were interconnected in such a way that the output of the floor was two analogue voltages representing the average X and Y coordinates of the person in the room. If he was standing on several switches, the outputs would be the averages of those switches. One disadvantage of the averaging process was that, if a switch became stuck on, it would bias the output considerably no matter how the participant moved. Such reliability problems prevented the system from being fully explored.

3.4.2.2 Graphics Hardware

The analogue position values from the floor were transmitted using frequency modulation over telephone lines to the Computer Center where the signal was demodulated by a TR-20 analogue computer. The signals were then fed into the Adage Graphic Display computer and used as input to one of a number of different programs. These programs generated visual images on the CRT where they were picked up by a television camera, transmitted to the gallery and there projected on the 8" x 10" screen. Note that this was the same video system used in the drawing except that no live image was superimposed.

3.4.2.3 Music Hardware

The sound system was basically the same used in Glowflow with the following differences:

1. There was no provision for switching speakers.

2. The output of the Moog was fed through one of four specially built envelope generators which provided different rates of attack, sustain, and decay for each sound.

3.4.3 Interaction

3.4.3.1 Floor Based Graphic Interaction

For this interaction only one person was allowed in the environment at a time. This requirement focused the participant's attention on the relationship between his behavior and the environments' response. If several people had been present, their awareness of each other would have competed with their awareness of the displays; plus, there would have been confusion about whose behavior was eliciting any particular response.

The participant's movements about the room generated graphic images that were displayed on the projection screen. In most of these his position in the room corresponded to the position of a cursor on the screen. Thus, he could draw on the screen by walking around the room. His relationship to the image was the same as the pen used with the data tablet.

The first few moments of each person's experience were regarded as a training period where he was presented with the simplest kind of relationship. As he moved around the floor, a projected dot would move correspondingly on the screen -- left for left, right for right, up for forward, and down for back. Then as the participant understood this relationship the computer would move into some more complex drawing relationships each followed by its own surprise or extension. Changes in the mode of drawing or transformation of the image occurred at prescheduled times.

There were a number of simple interactions based on this drawing relationship. All of the drawing variations used in the live drawing interaction were available. In addition the dot following the person's movements could leave other dots at each of the participant's past positions. Then as the person's past positions drew out a simple figure on the screen, he could either be limited to some arbitrary number of past positions or to the positions occupied during the most recent unit of time. In the first case, the dot representing the person in his current position was trailing around a tail of his recent past positions, and so he could, in a sense, interact with his own past. In the second case, if the viewer stood still, the number of positions he had occupied in the recent time increment decreased until his past caught up with him. Another event in this simple relationship was for the trail of dots to suddenly follow some arbitrary path so the man's past "went on without him".

3.4.3.2 Responsive Music

The music program designed by one of the author's students, Paul Hindes, was intended to provide an interactive background for the graphics. The person's behavior guided an ongoing music generation process, rather than providing a one-for-one responsive relationship. His behavior controlled parameters in a stochastic generation scheme. The conception was in terms of different domains of complexity, e.g. timbral and rhythmic. The designation of simple versus complex sounds and rhythms was a personal judgment by Paul Hindes. He arranged the basic waveforms, envelopes, and modulations in order of their complexity. The simplest sound was a pure sine tone, next the other pure tones, then the envelopes with the tones, then the modulation of the foregoing sounds. Similarly, rhythms were graded according to their complexity. The simplest would be silence, going to a regular beat, going to a more frequent regular beat; then periodic arhythmics were inserted until there was a very busy collage of sound. The two continua, tonal and rhythmic, were related to the position coordinates reported by the floor. Thus, each position in the room caused a certain kind of tonal and rhythmic event to be fitted into the generating program.

The actual choice of sound or rhythm was a random selection among the currently appropriate (in terms of complexity) choices which were heavily influenced by whatever the current sounds were. The rhythm was altered by increasing or decreasing the period of the current rhythmic scheme or by adding or deleting a rhythmic event from the existing scheme. The result was that while there was a deterministic scheme for choosing the levels of complexities, the actual sequence of sounds varied randomly over a period of time. There was no real large structure to the music, i.e. there was no concession to the concept of a "piece" that started when the participant entered and climaxed as he left. Rather the sound patterns would change slowly but perceptibly as his experience progressed.

3.5 Conclusion

There were a number of other capabilities implemented for this show. They are not described here either because they were more fully realized in later work or were not within the main thrust of this dissertation. For instance, the phosphorescent panel and superimposing of two live video images were effects that were included as backup in case one of the data links failed.

The significance of Metaplay lies in its commitment to real-time interaction. It identified and explored two ways that this interaction might be developed: between man and machine and between men via machines. Also important is the merging of video and data images. While this juxtaposition is occasionally attempted in film, the author knows of no other case where it has been done live. The many ramifications of this new video space will be cited throughout the remainder of this paper.

Metaplay was an ambitious project. A tremendous amount of equipment suddenly converged in the gallery. Most of it was being brought together for the first time. We were fortunate indeed that most of it worked. Even so, many of the possibilities remained unexplored or unfully exploited. At the end of the show, all of the borrowed or rented apparatus had to be returned to their disparate sources. And so while we had demonstrated what was possible with existing equipment, we were back where we started in terms of a continuing effort.

CHAPTER 4

PSYCHIC SPACE

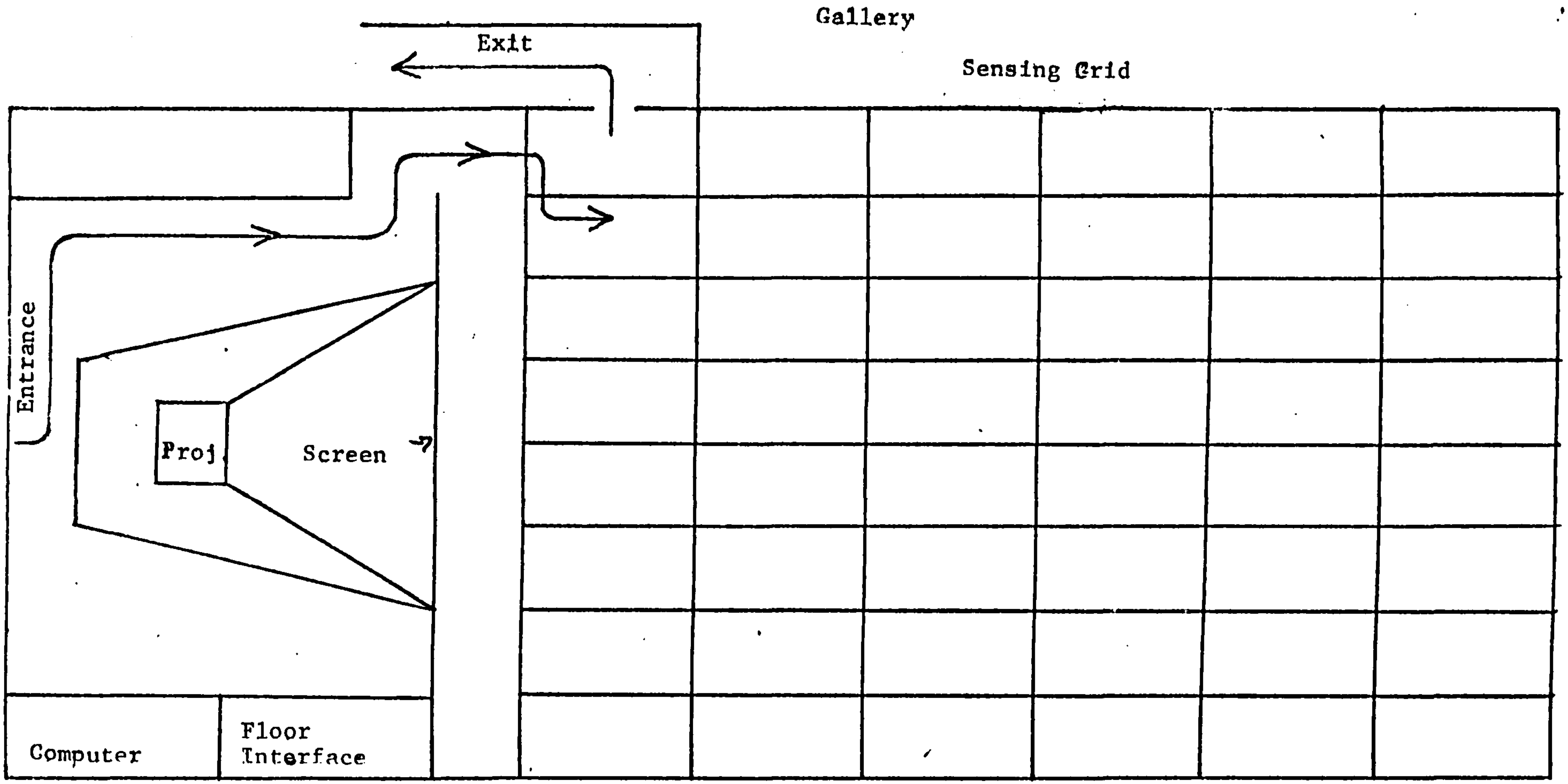
4.1 Conception

4.1.1 General

Psychic Space was designed to focus on one of the two alternatives presented in Metaplay. Computer facilitated interaction among humans was temporarily set aside to concentrate on man-machine interaction. Two different lines of development were explored. In one case the environment provided a richly composed interactive vignette; in the other it was thought of as an instrument for musical and visual expression. The different interactions will be described in separate sections below.

4.1.2 Physical Environment

The physical environment itself was a considerable improvement over the past (figure 4-1). The handling of the entry and exit was more



Psychic Space
fig. 4-1

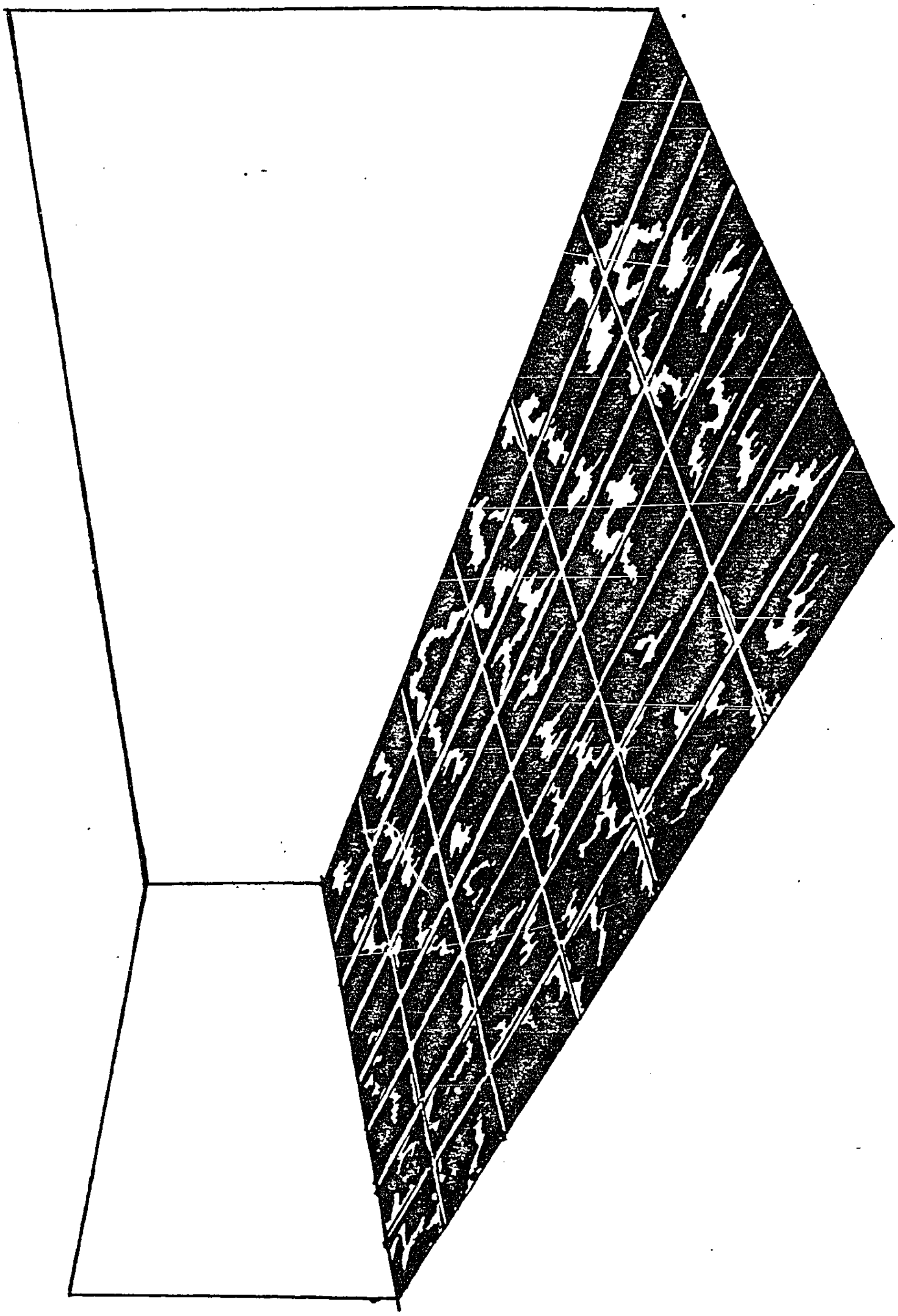
graceful and effective than before. Plus the 26' x 16' x 8' dimensions seemed appropriate, large enough to be explored yet small enough to maintain intimacy with all displays. The walls, ceiling and floor were covered with black polyethylene excepting the rear-view projection screen at one end and the phosphor panels at the other. The black plastic on the floor was not a single sheet but rather was used to cover the 2' x 4' modules of the sensing grid. The result was that the floor appeared as six rows of eight modules each. Visually this arrangement was very effective, suggesting the fact of function and the repetition of modular design (figure 4-2).

The end wall was covered with panels painted with a phosphorescent pigment. These walls could be illuminated by two "sun guns" (bright incandescent lights used for movie making). The wall at the opposite end was dominated by an 8' x 10' rear view projection screen. Behind the screen was a television projector. The computer and the rest of the circuitry were housed in a room to one side of the projection room. The entry way and exit were constructed so as to cut down the light entering the environment.

4.1.3 Hardware

4.1.3.1 Control Hardware

The central controlling hardware in this show was a PDP-11 with a 4K memory, 64 discrete inputs, and 64 discrete outputs. This machine had direct control of all sensing and sound in the gallery. In addition it communicated with an Adage AGT-10 Graphic Display Computer at the Computer Center. The Adage image was transmitted over video cable to



Flooring sensing modules in Psychic Space
fig. 4-2

the gallery where it was again rear-projected on the screen. The floor circuitry described below was common to all the interactions. Additional hardware specific to each of the interactions will be detailed in the separate sections describing them.

4.1.3.2 Floor Sensing

Position information from the floor was the basis for each of the interactions in this show. The sensing was done by a 16' x 24' grid of pressure switches. These switches were constructed in 2' x 4' modules. They were electronically independent so that the system was able to discriminate among individuals if several are present. This independence also made it easy for the programming to ignore a faulty switch until its module was replaced or repaired. Since there were 16 bits in the input words of the PDP-11, it was natural to read the 16 switches in each row across the room in parallel. Digital circuitry was then used to scan the 24 rows under computer control.

4.2 Approach #1 — Composed Environment -- Maze

With the Maze program the author was interested in demonstrating a carefully composed sequence of relations which would result in a coherent experience--if not a finished piece, at least an indication of what a finished piece might be like. It focused completely on the interaction, just one person interacting with the environment. We generally only showed the Maze to people who arrived alone. The experience consisted of navigating a projected maze by moving about the room. The interest came from the Maze's response to the person's efforts to walk it. The Maze played with his intention of walking it and even with his act of walking.

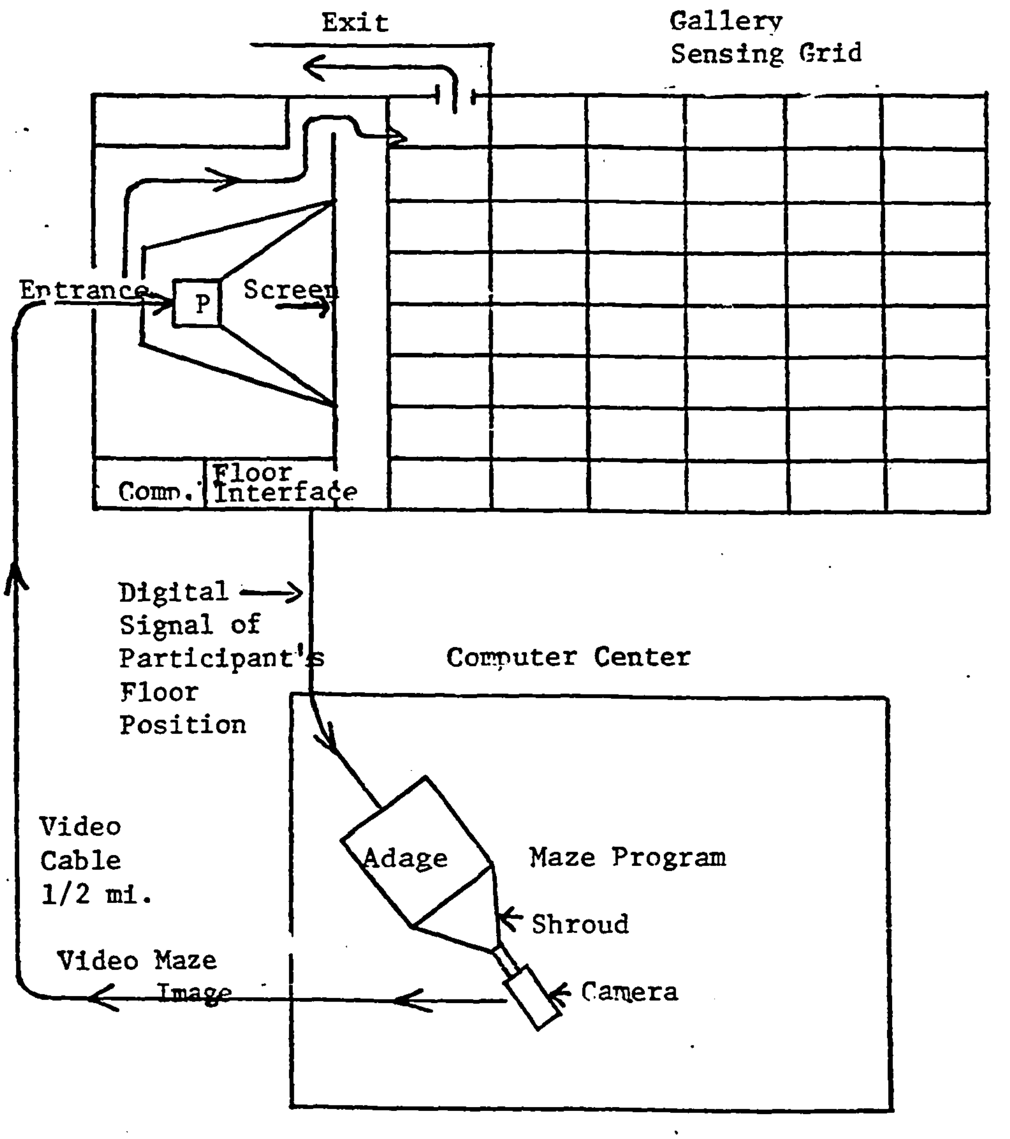
4.2.1 Hardware

The Maze itself was not programmed on the PDP-11. Rather, it was running on the Adage located a mile away in the Computer Center. The PDP-11 transmitted the participants floor coordinates across an audio cable to the Adage. The data was transmitted asynchronously as a serial bit stream of varying pulse widths. The Adage generated the maze image which was picked up by a TV camera and transmitted via a video cable to the Union where it was projected rear-view to a size of 8' x 10'. These communication links are shown in Figure 4-3.

4.2.2 Interaction

4.2.2.1 Initialization

The first problem was simply to educate the person to the relationships between the floor and the screen. Before the maze appeared, a diamond with a cross in it represented the person's position. As he moved, it moved: left for left, right for right, up for back, and down for forward. The next step was to move him to the starting point of the maze (figure 4-4). It would seem that this requirement could have been avoided by making the maze around his current position. This is true, but for the sake of programming convenience we had a means of getting him to the preferred starting



Data and Video Communication for Psychic Space
fig. 4-3

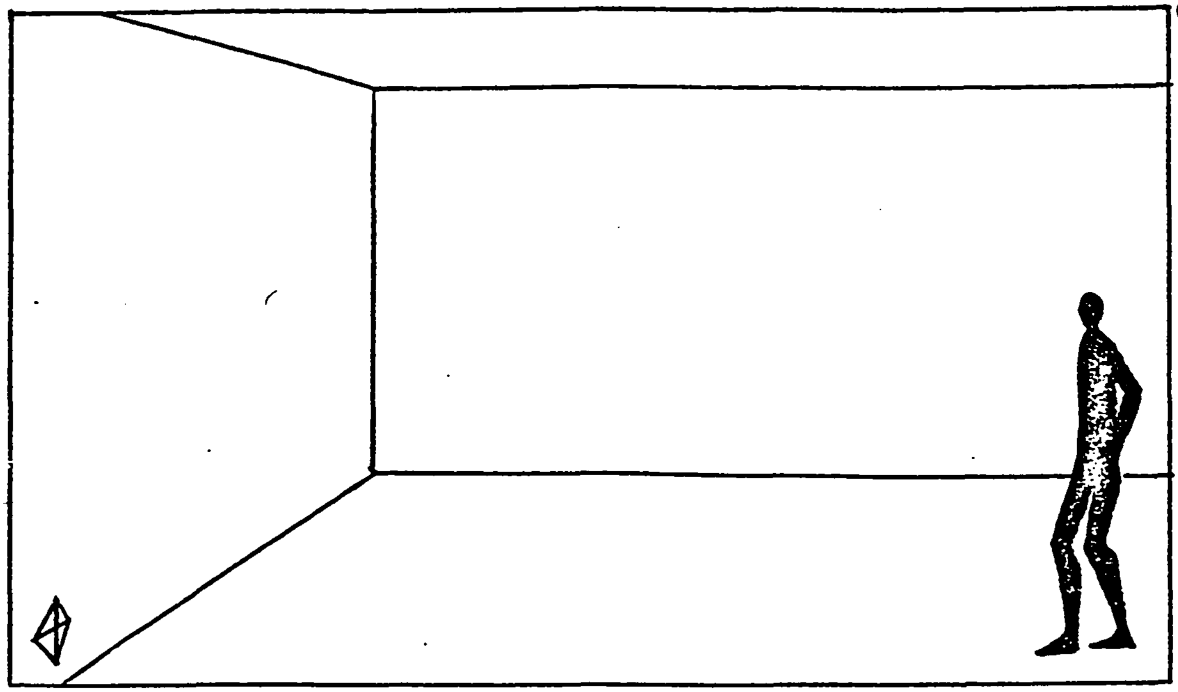


fig. 4-4a

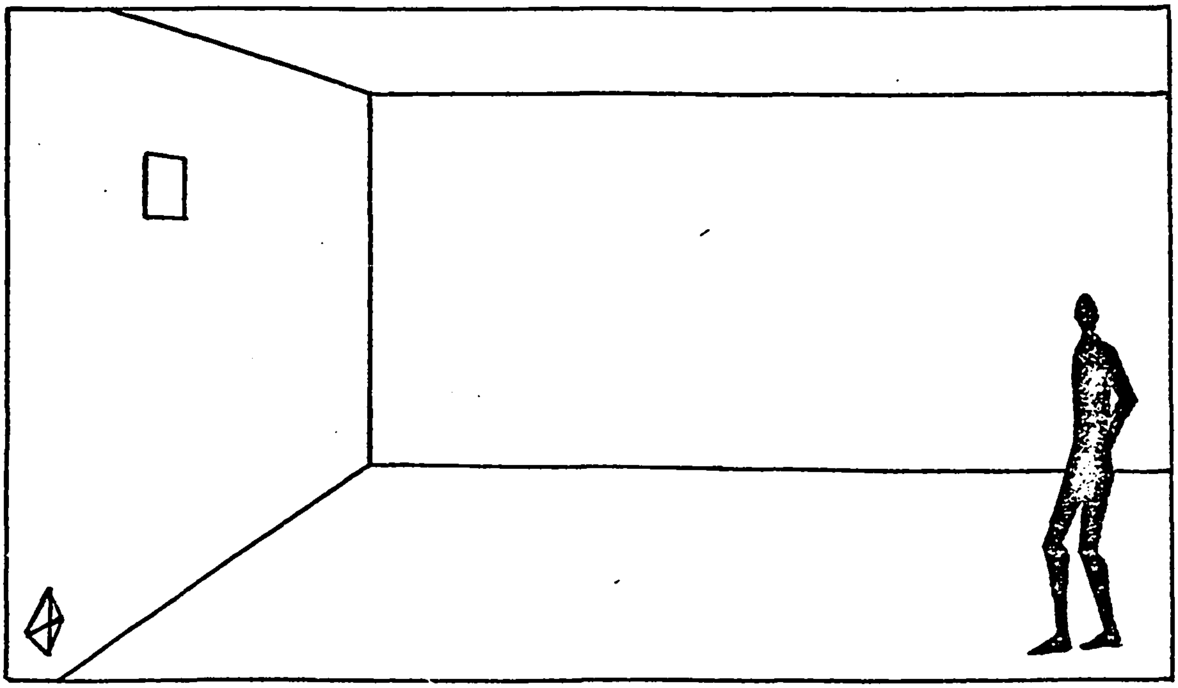


fig. 4-4b

Composed Environment--Maze
fig. 4-4a & 4-4b

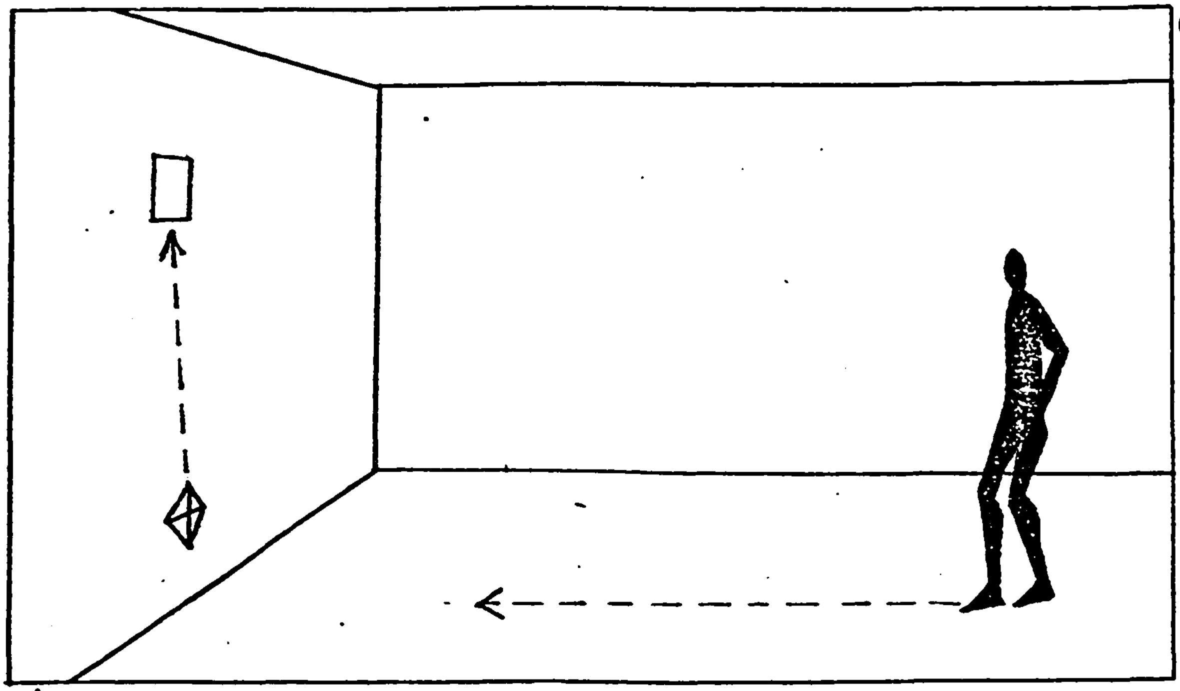
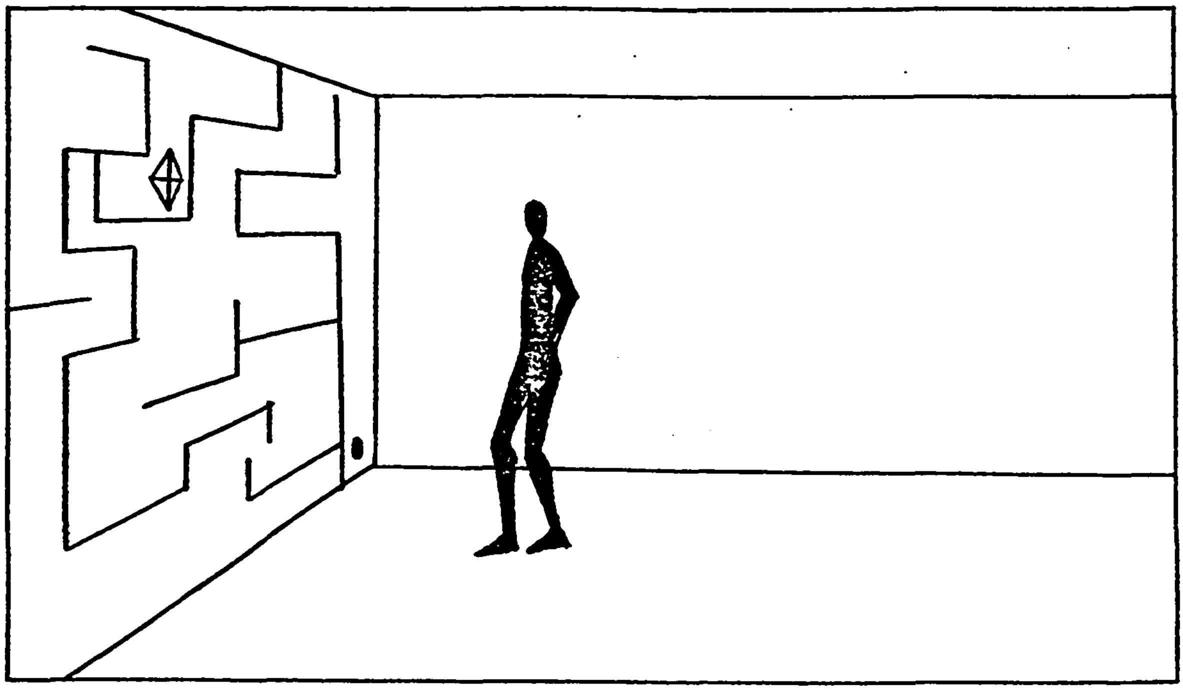


fig. 4-4c



fig, 4-4d

Composed Environment--Maze
fig. 4-4c & 4-4d

starting position. We placed another object in the display at the position that would be the starting point of the Maze were it displayed. With this lone object on the screen, the viewer invariably wondered what would happen if he went there. When he got there, the object vanished and the maze appeared with him at the starting point. At this moment he was able to walk the maze. It seems to be a fact of human nature that when a man is confronted by a maze he is willing to walk it. We had no one who asked why he should want to walk a maze.

4.2.2.2 Software Boundaries

The problem confronting the programmer was how to enforce the boundaries of the maze. There were no physical boundaries in the room; however, the computer was aware of the position of the observer and the locations of all displayed boundaries. Therefore, the computer could change the maze in some way when a boundary was violated. Several different responses to boundary violations were programmed:

1. The boundary could move.
2. It could stretch elastically.
3. It could move until a new passage was created.
4. It could disappear and changes occur in the rest of the maze so that no advantage was gained by crossing it.
5. The symbol representing the person could split in half at the boundary with one half held stationary while the other half, the alter ego, tracked him according to the usual rules. However, he could make no progress on the maze until he returned to the original symbol and got himself back together.

Even when the participant was moving legally, there were changes in the program contingent upon his position:

1. Several times as he approached the goal the maze would change in such a way as to thwart immediate success.

2. The relationship between the floor and the maze was altered so that movements that once resulted in up to down motion then resulted in left to right and vice versa.

3. The symbol representing the participant could remain stationary with the whole maze moving around him as he moved around the room.

Even at the end, success was not allowed. As he closed in on the goal, additional boundaries appeared both in front and behind him, completely locking him in. At this point the maze slowly shrank down to nothing. While the goal could not be reached, the composed frustrations made the route interesting.

4.2.2.3 Experience

The Maze experience conveyed an unusual set of feelings. The video display space seemed cold and distant. The sense of detachment was enhanced by the displaced feedback: movement on the horizontal plane of the floor was translated onto the vertical plane of the screen. The popular stereotype of dehumanizing technology seemed fulfilled. However, the maze idea was engaging and people became involved willingly. The lack of any other sensation focused their attention completely on this interaction. As the experience progressed, their perception of the Maze changed. From the initial impression that it was a problem for them to solve, they moved to the realization that the maze was a vehicle for whimsy, playing with the concept of a maze and poking fun at their compulsion to walk it.

4.3 Approach #2 -- Environmental Instrument

In these interactions the goal was to encourage the interactants to express themselves through the environment. For the first few minutes the floor of the environment became the keyboard of a musical instrument which the participants could play by moving around the room. Then the music response ceased and the computer's attention focused on the far end of the room. There the group could compose images by freezing their own silhouettes on the phosphorescent panels.

4.3.1 Interactive Sound

4.3.1.1 Hardware

The audio output was quite simple. All that was actually used was an 8-bit D-to-A converter fed into a voltage controlled oscillator with selectable triange, sawtooth, and pulse output. An additional audio output was provided by taking the signal used to trigger an ultrasonic burglar alarm and amplifying that. This signal was the doppler shift of the projected frequency reflected off moving individuals. Since the doppler signal was a very low frequency it was desirable to differentiate it to boost the frequencies and thus the pitch. By moving his body, a person would get low sounds directly corresponding to his movement. Although more grandiose things were planned and physically built, they were not tied together into a working hardware-software system in time for the show.

4.3.1.2 Input

The program started automatically when someone entered the room. For the first minute the floor was a keyboard with the sounds responding to his footsteps as he moved around the room.

We experimented with a number of different schemes for actually generating the sounds. This required a thoughful look at the arcane art of footstep analysis. In sampling the floor 60 times per second we discovered that a single footstep consisted of as many as four discrete events: lifting the heel, lifting the toe, putting down the heel, and putting down the ball of the foot. The first two were dubbed the "unfootstep." We could respond to a person's average position, that is, the X and Y averages of all of the switches he was standing on or we could respond to each footstep or unfootstep as it occurred. A number of such response schemes were tried, but the clearest was to start each tone only when a new switch was stepped on, and then to terminate it on the next "unfootstep" so that it was possible to get silence by jumping, or by lifting one foot, or by putting both feet on the same switch.

4.3.1.3 Interaction

The typical reaction was instant understanding followed by a rapid-fire sequence of steps, jumps, and rolls. This phase was followed by a slower more thoughtful exploration of the environment. Once the initial enthusiasm was exhausted, more subtle and interesting relationships could be developed. After calming down the participant could discover that the room was organized with the high notes at one end and lows at the other. Then periodically this keyboard was rotated 90 degrees, going from side to side instead.

After a longer period of time an additional feature came into play. If the computer discovered that a person's behavior was characterized by a short series of steps punctuated by a relatively long pause, then it would use the pause to establish a new kind of relationship. The sequence of steps was responded to with a series of notes as before; however, during the pause the computer would echo these notes. If he remained still during the pause the computer assumed that he understood and continued to echo with variations. His next sequence of steps was again echoed but this time at a noticeably higher pitch. Subsequent sequences were repeated several times with different variations each time. This interaction was experimental and extremely difficult to introduce clearly with feedback alone, i.e. without explicit instructions. The desire was for a man-machine dialogue resembling a soft-shoe due from an old movie or the guitar due in the recent movie "Deliverance". It was hard to consistently detect or shape the appropriate behavior. Nevertheless, the author feels that the dialogue was a powerful experience, especially when it was discovered by the participant without any explanation.

4.3.2 Phosphorescent Shadows

4.3.2.1 Hardware

The phosphorescent panels at the end of the space were illuminated by two sunguns under computer control. An ultrasonic motion detector was used in conjunction with the floor to determine whether the person was standing completely motionless in front of the panels.

4.3.2.2 Interaction

When the lights were turned on the whole wall would glow except where the participant's body had blocked the light. The result was that a detailed life-sized silhouette was left frozen on the wall after the light went off. This interaction was the simplest and the least computer-like; however, it served its purpose as backup in case the more complex systems weren't working.

The phosphors were also used in conjunction with the floor based sound responses. The first part of the experience would be devoted to the sound interaction followed by a switch to the phosphors. To accomplish the transition from one interaction to the other, it was necessary to get the participant to move to the end of the environment.

When given enough time it was not too difficult to get him there by responding with sounds only to movements in that direction. In the darkened environment with no visual cues people were exceptionally quick to respond to the auditory cues we used to guide them. Unfortunately, at the times when we had people waiting in line we could not rely on such subtle means. In order to reduce each person's time we had to give him explicit instructions about operating the phosphors.

Even when instructions were given it was useful for the computer to warn the participant when the light was about to flash so he could have time to prepare his pose. This was accomplished by preceeding the light with a sequence of ascending pitches. At the end of the sequence the light came on for about a second. After the light went off, he was given some time to admire his shadow before the process was repeated.

4.3.2.3 Glowmotion

Since Psychic Space, the phosphors have been used in a separate show called Glowmotion which did not involve the computer. In this show an extremely bright flashtube was used instead of the sunguns. The flash produced was so brief that it was possible to capture a person's shadow as he jumped in the air. With this system in the computer controlled environment, the need to be motionless would not exist. The computer could sense when people were jumping and flash the light at that moment. Also, as more response modes are integrated there will be no need to guide people to the phosphors. The phosphor system will be used only with people who are in the required location. The others would receive other responses. Then the phosphors become a dramatic surprise for a few people rather than everyone's expectation. For instance, if the computer were to get someone wildly flailing his arms to get an audio response from an ultrasonic based system, it would be effective to abruptly stop the sound and flash the light, catching him in mid-gesture. Now that the phosphors are perfected they recede in importance, becoming just one element in the environment's repertoire.

4.4 Conclusion

While Psychic Space still consisted of several separate systems, the author felt that things were starting to come together. Some integration of the separate response systems did occur, particularly with the phosphors which used multiple sensors and audio output to ensure that the lights flashed at the best moment. In spite of the fact that it was somewhat cold and "cybernetic," the author was pleased with the Maze program. It successfully engaged each person in an intent interaction which led them to a different understanding of the relation as time passed. They started with the assumption that they would walk the maze, then felt the environment was playing with them, and finally realized that the environment was simply playing with the idea of a maze.

In Psychic Space we were able to fine tune some of the interactions. We also got a better feeling for the mechanics of putting on a show, of getting people in and out, and of minimizing the amount of verbal instruction required. At the same time the author started to feel some misgivings about the concept of a show. A show like this inevitably attracts more people than it can handle. Even without any publicity, Metaplay and Psychic Space Always had long lines. The result was that we had to gear the experience to handle the crowds, by making it shorter and by allowing in more people at a time. But this compromised the whole point of the work, personal interaction. So the author is now more interested in creating a standing facility which would serve as both a compositional tool and a continuing showplace. Such a facility will be described in a later chapter.

CHAPTER 5

DEFINITION AND AESTHETICS

5.1 Introduction

This chapter defines the responsive environment and identifies the aesthetic characteristics of the medium. The initial discussion points out weaknesses in our current media. Responsive environments are defined as partially compensating for these weaknesses. The roles of the "artist" and the "audience" within the medium are then compared to their respective roles in the past. Finally, several aesthetic problems which are uniquely important in this medium are described.

5.2 Aesthetic Need

Responsive environments are particularly timely because of the current state of the Arts. For some time, artist have lamented the diminishing effectiveness of their traditional tools.

5.3 Definition - Response is the Medium

The medium is a commitment to complete real-time interaction between man and machine. Perceptual, responsive, and control systems comprise the hardware elements of the medium. It accepts inputs from or about the participant and then outputs in a way he can recognize as corresponding to his behavior. The relationship between inputs and outputs is arbitrary and variable, allowing the artist to intervene between the participant's action and the results he perceives. Thus, for example, the participant's physical movement can cause sounds or his voice can be used to navigate a computer defined visual space. It is the composition of these relationships between action and response that is important. The beauty of the visual and aural responses is secondary. Response is the medium!

5.3.1 Inputs - Perception

The distinguishing aspect of the medium is, of course, the fact that it responds to the viewer in an interesting way. In order to do this, it must know as much as possible about what the participant is doing. It cannot respond intelligently if it unable to distinguish various kinds of behavior as they occur. For example the environment might be able to respond to:

1. The participant's position
2. The volume or pitch of his voice
3. His position relative to his prior position
4. The time elapsed since his last movement

5.2.1 The Saturation of the Senses

Among art critics it is often said that painting is dead. Art historian Jack Burnham suggests that Art itself is dead. To these obituaries, I would like to add my own somewhat hyperbolic statement and then examine to what extent it is true.

The visual is dead! We are constantly bombarded with visual images by TV, magazines, movies, etc.. Not only is there a quantity of visual images but it is hard to deny there is quality as well. Most of the images we see are carefully crafted for maximum effect and many are beautiful. The result is that we cannot take in all we see. Numbed by the onslaught of visual information, insulated by categories and filters, vision, our most heavily trafficked sense, is not capable of receiving "real" information, i.e. Art. Sending a message through vision alone is like sending it through channels; you can be sure that it will be processed correctly but also that it will be treated as routine. To touch a person today, you have to slip past his defenses and involve him in an unfamiliar way.

5.2.2 Beyond Interpretation

Oddly, Art History, Art Criticism, and Art Appreciation have become deterrents to experiencing Art. Over and over students leaving the environments have asked, "I really liked it, but what did it mean?" For some reason they felt that what had happened should be immediately reducible to words. In fact, there is a tendency to accept events in terms of the words that will be used to describe them. There is a place for a medium which can resist interpretation. The environment can take steps to individualize the responses and thus thwart analysis. If each person has a different experience, he will feel less pressure to arrive at the "right" interpretation. Since each person will move about the space somewhat differently, each will receive different feedback even if the program is exactly the same. If there are many programs alternating control of the environment, each participant's adventure will be unique. Thus, two people can exchange experiences, but since they have had no common experience they cannot analyze it to death.

5.2.3 Active vs. Passive

There is another way that responsive environments answer a cultural need. All of our traditional art forms have one thing in common: they assume a passive audience. Passiveness was appropriate when men toiled physically. However, after centuries of effort we have all but eliminated the necessity for physical exertion. Ironically, since our bodies require a certain amount of exercise for health, we face a new problem -- how to reintroduce labor into our lives. Sports do this for some, but almost none of the sports are actually considered good exercise. Millions are doing mindless exercises and jogging. We have a place for new forms of art and entertainment which will also satisfy our bodies' needs.

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1. The participant's position
2. The volume or pitch of his voice
3. His position relative to his prior position
4. The time elapsed since his last movement

5. Every third movement

6. Rate of movement

7. Posture

8. Height

9. Colors of clothes

Or, if there are several people in the room, it could also respond to

1. The distance separating them

2. The average of their positions

3. The computer's ability to resolve them, e.g. respond differently when they they are very close together.

At a higher level, the machine can learn about the individual and judge from its past experience with similar individuals just which responses would be most effective.

At first, these systems will be constrained by the total inability of the computer to make certain very useful and, for the human, very simple perceptual judgments, such as whether a given individual is a man or a woman or is young or old. The perceptual system will define the limits of meaningful interaction, for the environment cannot respond to what it cannot perceive. To date the sensing systems have included pressure pads, ultrasonics, and video digitizing.

5.3.2 Outputs - Responsive Displays

As mentioned before, the actual means of output are not of primary importance in this medium as they would be if the form were conceived as solely visual or auditory. In fact, it may be desirable that the output not qualify as beautiful in any sense, for that would distract from the central theme: the relationship established between the observer and the environment. Artists are fully capable of producing effective displays in a number of media. This fact is well known and so to do it again produces nothing new. What is not known and remains to be tested is the validity of a responsive aesthetic. This is a more interesting question for artist and public alike, since the design of intelligent, behaving systems is now a common goal for both Science and Art.

It is necessary that the output media be capable of displaying intelligent or at least composed reactions so that the participant knows which of his actions provoked it and the relationship of the response to his action. The purpose of the displays is to communicate the relationships that the environment is trying to establish. They must be capable of great variation and fine control. The response can be expressed in light, sound, mechanical movement, or through any means that can be perceived. So far computer graphics, video generators, light arrays, and sound synthesizers have been used.

5.3.3. Control and Composition

The control system includes hardware and software control of all inputs and outputs as well as processing for decisions that are programmed by the artist. He must balance his desire for interesting relationships against the commitment to respond in real-time. The simplest responses are little more than direct feedback of the participant's behavior, allowing the environment to show off its perceptual system. But far more sophisticated results are possible. In fact, a given aggregation of hardware sensors, displays and processors can be viewed as an instrument which can be programmed by artists with differing sensitivities to create completely different experiences. For instance, the environment can be thought of in the following ways:

1. An entity which engages the participant in a dialogue. The environment expresses itself through light and sound while the participant communicates with physical motion. Since the experience is an encounter between individuals, it might legitimately include greetings, introductions, and farewells -- all in an abstract rather than literal way. The problem is to provide an interesting personality for the environment.

2. A personal amplifier. One individual uses the environment to enhance his ability to interact with those within it. To the participants the interaction might appear similar to that in Number 1. The result would be limited by the speed of the artist's response but improved by his sensitivity to the participant's moods. The live drawing interaction in Metaplay could be considered an example of this approach.

3. An environment which has sub-environments with different response relationships. This space could be inhabited by artificial organisms defined either visually or with sound. These creatures would interact with the participants as they moved about the room.

4. An amplifier of physical position in a real or artificially generated space. Movements around the environment would result in much larger apparent movements in the visually presented space. A graphic display computer can be used to generate a perspective view of a modelled space as it would appear if the participant were within it. Movements in the room would result in changes in the display, so that by moving only five feet within the environment, the participant would appear to have moved fifty feet in the display. The rules of the modelled space can be totally arbitrary and physically impossible, e.g. a space where objects recede when you approach them.

5. An instrument which the participants play by moving about the space. In Psychic Space the floor was used as a keyboard for a simple musical instrument.

6. A means of turning the participant's body into an instrument. His physical posture would be determined from a digitized video image and the orientation of the limbs would be used to control lights and sounds.

7. A game between the computer and the participant. This variation is really a far more involving extention of the pinball machine, already the most commercially successful interactive environment.

8. An experiential parable where the theme is illustrated by the things that happen to the protagonist -- the participant. Viewed from this perspective, the Maze in Psychic Space becomes pregnant with meaning. It was impossible to succeed, to solve the maze. This could be a frustrating experience if one were trying to reach the goal. If, on the other hand, the participant maintained an active curiosity about how the Maze would thwart him next, the experience was entertaining. Such poetic composition of experience is one of the most promising lines of development to be pursued with the environments.

5.3.4 Implications of the Art Form

5.3.4.1 For the Artist

For the artist the environment augurs new relationships with his audience and his art. He operates at a metalevel. The interactant provides the direct performance of the experience. The environmental hardware is the instrument. The computer acts much as an orchestra conductor controlling the broad relationships while the artist provides the score to which both performer and conductor are bound. This relationship may be a familiar one for the musical composer, although even he is accustomed to being able to recognize one of his pieces, no matter who is interpreting it. But the artist's responsibilities here become even broader than those of a composer who typically defines a detailed sequence of events. He is composing a sequence of possibilities, many of which will not be realized for any given participant who fails to take the particular path along which they lie.

Since the artist is not dedicated to the idea that his entire piece be experienced he can deal with contingencies. He can try different approaches, different ways of trying to elicit participation. He can take into account the differences among people. In the past, Art has often been a one-shot, hit-or-miss proposition. A painting could accept any attention paid it, but it could do little to maintain interest, once it had started to wane. In an environment the loss of attention can be sensed as a person walks away. The medium can try to regain attention and upon failure, try again. The piece has a second strike capability. In fact it can learn to improve its performance, responding not only to the immediate moment but also the entire history of its experience.

5.3.4.2 For the Participant

The participant is confronted with a completely new kind of experience. He is stripped of his informed expectations and forced to deal with the moment in its own terms. He is actively involved, discovering that his limbs have been given new meaning and that he can express himself in a new way. He does not simply admire the work of the artist; he shares in its creation. The experience he achieves will be unique to his movements and may go beyond the intentions of the artist or his understanding of the possibilities of his piece.

5.3.4.3 For the Public

5.3.4.3.1 Early Warning

Using this medium as a vehicle for implicit content raises the question of what is communicated by the medium itself and what it can be used to communicate. First the medium presents some unavoidable facts about current technology. For better or worse our technology is going to perceive us. It is going to seek to communicate with us. The relationship is going to get cozier and more intimate as time passes. The responsive environment introduces some of the most up-to-date technology in a way which makes its implications palpable. Since it is neither technical explanation nor ignorant histronics about dehumanizing technology, the experience can serve as an early warning system for someone who seeks to know nothing specific but would like some feeling for what he may be called upon to adapt to.

5.3.4.3.2 Technology for Fun

More important than the specific knowledge a person may gain about technology is the attitude that is conveyed. The environment is technology for fun. Americans are incredibly attuned to the idea that the sole purpose of technology is to solve problems. We seem unable to grasp that only by completely integrating our technology with the whole of our lives can we understand its implications sufficiently to use it with confidence to solve problems. Consequently, we buy our entertainment equipment almost exclusively from other countries which are better able to see the implications of our inventions in terms of day-to-day life.

In addition, these environments illustrate ways that the technology can be personalized and humanizing. It is possible to program the environment so that each person has a dramatically different experience not only because he acts differently but because the relationships which govern the interaction are different.

Finally, in an exciting and frightening way, the environments dramatize the extent to which we are savages in the world which our technology creates. The layman has extremely little ability to define the limits of what is possible with current technology and so will accept all sorts of cues as representing relationships which in fact do not exist. The constant birth of such superstitions indicates how much we have already accomplished in mastering our natural environment and how difficult the initial discoveries must have been.

This medium also makes a serious indictment of our current style. It offers nothing to the passive audience. A passive individual can enter and, ignoring the invitation to become involved, leave having experienced nothing. In some compositions only those seeking involvement will be satisfied while in others the environment may be willing to cajole the participant into a conversation. The decision is up to the artist and depends upon his attitude toward people.

5.4 Design Considerations

5.4.1 Multiple People

In designing these experiences there are a host of considerations. First, one must consider how many people are to participate at a time. If there are several, the relations between people start competing with those defined by the hardware. If response is the medium, it is clearest when one person is alone with the environment. Also, the experience is more involving for a solitary person because he will be less self-conscious and so more susceptible to involvement. With a number of people in the space there must be a way for each to associate his actions with the corresponding response by the environment; otherwise, the responsiveness becomes meaningless.

5.4.2 Space

To date the author has worked with bounded dark spaces which have no structural content whatsoever, meaning that the rooms are empty and rectangular. By choosing a shaped space one must compose around it and take some of the ideas suggested by the shape. So the shape determines the content. The empty rectangle does have the advantage of being general; physical space is eliminated as a concern and the response is the only focus. So far the walled space is much like the frame for a picture or a pedestal for a sculpture; it separates the composition from the rest of the world. It allows the artist to completely control the environment. If the environment can be made completely dark, then the participant can perceive only what the artist chooses to show him. The darkness also helps to free people from their inhibitions, making them more playful.

There are situations where it would be desirable to bring responsiveness into the everyday environment, particularly as a sort of happening or an active space that was delineated only by its effects. But in general the author feels that the new form requires focused attention so that it cannot be relegated to the status of responsive Muzak.

5.4.3 Explanations

The author feels that it is desirable to avoid giving any explicit instructions. New relations should be introduced by experience and understood by exploring them. Since the discovery process must proceed at its own pace, this requirement is not consistent with galleries which must often pass large numbers of people through an exhibit. However, the intrusion of explicit explanation is not worth the time saved, for unexpectedly, the most obtrusive presence of all is that of an authoritative human. This reminds us that dehumanizing is usually the result of human decisions not the technology itself.

One situation where explanation might be required is at the end of an experience. The problem of ending a piece exists in any medium. The ending should be self-explanatory and consistent with the rest of the piece. The most elegant solution so far has been to respond only to the motion toward the exit. This strategy has invariably resulted in people moving in the desired direction. The experience is over when the person finds that he is not longer in the environment.

5.5 Conclusion

The responsive environment opens a new dimension for the arts just at the moment when existing forms seem to have become important. By focussing on live interaction it allows the artist to compose a rich variety of the alternatives rather than a set of final decisions. The freedom from finality allows a piece to grow, to learn. The artist is its sire and each participant a member. The responsive environment is more than an art medium, it is a whole new realm of human experience.

The fantastic possibilities it offers may take centuries to develop. The next few chapters identify the tools which must be built to establish this new tradition.

CHAPTER 6

REAL-TIME INPUTS

6.1 Introduction

By definition the responsive environment responds to the behavior of the participants within it. This chapter outlines the hardware and software the computer can use to perceive the behavior. The input process is defined and general design considerations discussed. A large number of hardware sensors are described along with their most significant advantages and disadvantages. The hardware sensors deliver perceptual information to the computer which must interpret it before deciding how to respond. The problems facing the interpreting software are touched on using examples drawn from experience with the floor sensors used in Psychic Space. Throughout this chapter an effort is made to show the effect of these hardware and software decisions on the interactions between the environment and the participants.

6.1.1 Definition

The hardware inputs come from two sources: explicit controls such as buttons or levers operated by the spectators or artist and sensors used by the computer to perceive the state of the environment. These inputs, their associated circuitry, and the interpreting software comprise what will hereafter be referred to as the "sensory" or "perceptual" system.

This system may yield both static and dynamic information about the participants. The static information includes attributes such as height, weight, and color of clothing which the participant cannot change or control during the experience. The dynamic quantities like position in the room, rate and direction of movement, and pitch or volume of the voice can be controlled and thus form the basis of the interaction. The computer can respond to a static attribute, but this response will be less meaningful to the participant because he is unlikely to identify its cause and cannot control the effect.

The apprehension of events in the environment is a two step process: first the conversion of sensory transducer information (switches, states, durations, amplitudes) into logic levels compatible with computer circuitry and second the software interpretation of this data to identify the events of interest.

6.1.2 Importance

The inputs define the limits of meaningful interaction between the computer and the participants. The environment's perceptual system determines what the computer knows and thus what it can respond to. If the computer is only aware of the pressure of the participants' feet, any armwaving will be invisible to it and thus irrelevant to the interaction. Behavior which evokes no response is less likely to recur. After the first few minutes the participant will typically be behaving only in those ways the computer can perceive and thus respond to. Thus, the mode of sensing can give importance to a certain kind of behavior. Switching to a different mode of sensing creates a new focus, constitutes an important aesthetic event, and changes the nature of the ensuing interaction.

6.2 Design Considerations

Before enumerating the many perceptual hardware options some general design considerations will be discussed. These points should be kept in mind while reading the system descriptions that follow.

6.2.1 What Should be Sensed?

Since the goal of the environment is to physically involve the participant in a relationship he can understand, the computer must be able to perceive his behavior. It should also be possible for the participant to recognize which aspects of his behavior are eliciting the responses. Initially the computer should concentrate on the perception of gross physical movements and postures because the participant will only be aware of this level of behavior. The first experience with feedback usually leads a new participant into a rapid-fire sequence of large movements. Only after this phase has run its course is he ready for more subdued and subtle relationships involving small behavior such as facial expressions.

At any time responses to such static attributes as height or weight are not very meaningful because the participant will not be aware of how he caused them and he will be unable to change them. However static information may be useful for identifying and discriminating people when several are present, helping the computer individualize its responses.

6.2.2 Resolution

The design of the perceptual system requires a tradeoff between the need for the computer to know as much as possible about the state of the environment and its commitment to respond in real-time.

The responsive sculpture described earlier suffered from inadequate sensory systems, usually consisting of just a few discrete sensors such as photocells or proximity switches, providing little information about what was going on in their vicinity. There was no way such sculpture could offer more than the most meager, knee-jerk kinds of response. With input from only six pressure pads, Glowflow was also unable to inadequately sense what was happening within its space.

In order to behave more intelligently, the processor must have a wealth of information on which to act. It must be sensitive to small movements, able to identify individuals if several are present, and capable of keeping track of those individuals as they move around. On the other hand, the sensory system should not provide too much information. Unneeded detail will require extra processing which might be better used interpreting the input or enriching the output responses. The robot Shakey receives and processes so much visual information that it is unable to behave in real-time, requiring minutes to react to a single percept. Where the sensor provides more information than the computer can handle there must be some way the computer can focus on parts of it, to keep the amount of data consistent with the real-time nature of the medium.

6.2.3 Structure

The sensory hardware should facilitate efficient processing of its inputs by the computer. Arranging the sensors in a rigid format allows the computer to preserve relationships between the inputs of different sensors, especially if that external format can be realized directly in the internal computer model. The floor in Psychic Space was a 24 x 16 grid of sensors. The internal representation was an array of twenty-four 16 bit words in the PDP-11. This correspondence made it extremely convenient to respond to position and changes in position. Some of the alternatives described below would not have provided such manageable data.

6.2.4 Multiple People

If more than one person is to be allowed in the environment at a time, it is desirable to be able to identify each and to respond uniquely to each person's movements. Only in this way can each individual recognize the results of his behavior as distinct from that of others. The ability to resolve individuals in a group does not preclude responding to the group as a whole or to relationships among members of the group; such information can be easily derived from the data about the individuals. A number of approaches to this problem are suggested in the ensuing examples.

6.2.5 Should Sensors be Hidden or Obvious?

The choice of input method includes one purely aesthetic consideration: should the participant be aware of exactly how he is being perceived by the machine? If the answer is affirmative then there are several degrees of obviousness. Most blatant would be to have explicit controls such as buttons or levers around the room. Or the sensing system might necessitate the participant carrying or wearing something to help the computer perceive him. Less obtrusive but still obvious would be to use a method like a laser beam which can be seen as it scans the space looking for people who will reflect its light back. There are many possible criteria for this decision. It depends on the goals of each particular interaction, whether it is allowable or even desirable for the sensing system to intrude. The author shies away from explicit controls and encumbering devices but recognizes that a magic wand, a Hobbit's ring, or a blinking cap might add to the experience, particularly for children.

6.3 Behavior Sensors

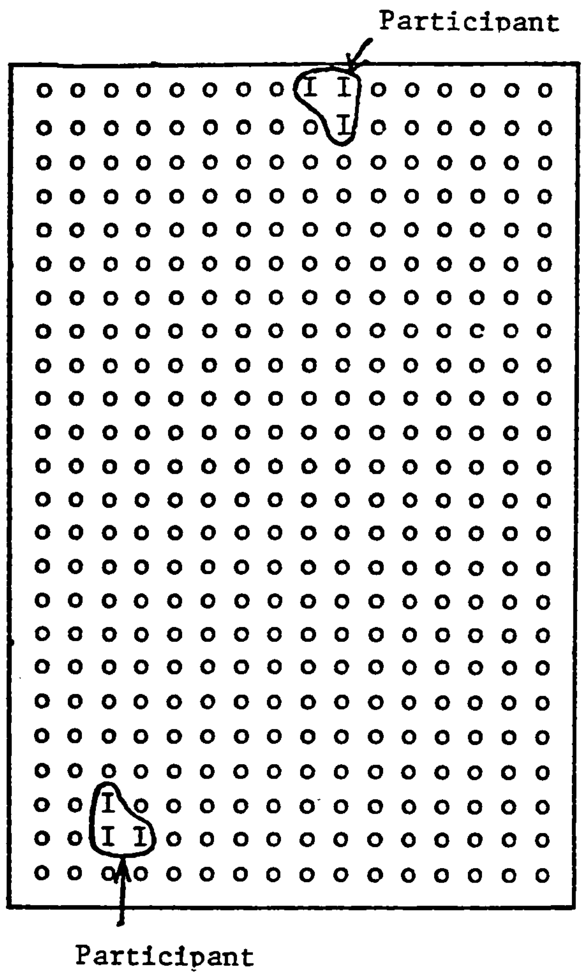
6.3.1 Position

6.3.1.1 Grids

The location of the participant can be determined in a number of ways. A grid of individual presence sensors distributed throughout the space is perhaps the most direct approach. Each of these sensors can be designed to detect either the participant's pressure on the floor, his body capacitance, or light his body blocks or reflects. Each of these sensors opens or closes an electronic switch and the array of switch values is then read into the computer. In these systems a person appears as a number of ones in a field of zeroes (figure 6-1). This approach makes the computer sensitive to the position of the participant's feet. It completely ignores any motion of the rest of the body. If a number of people are present they can be discriminated as long as they are not too close together. Velocity and direction of movement can be inferred from a succession of grid samples.

6.3.1.2 Triangulation

Position can also be determined by triangulation, i.e., if a person's distance from each of three points is known then his location can be computed. His distance from a given point can be determined in several ways. First, if he were to wear a light, a radio, or ultrasonic source, the amplitude of that signal at the sensor would be a function of his distance from it. By giving



Participants' feet are seen by the computer as ones in a field of zeroes.

fig. 6-1

each person an emitter with a distinguishing frequency of light or sound such a system could keep track of several people at a time. However, there would be a problem with one person blocking another's signal unless the sensors were mounted near the ceiling.

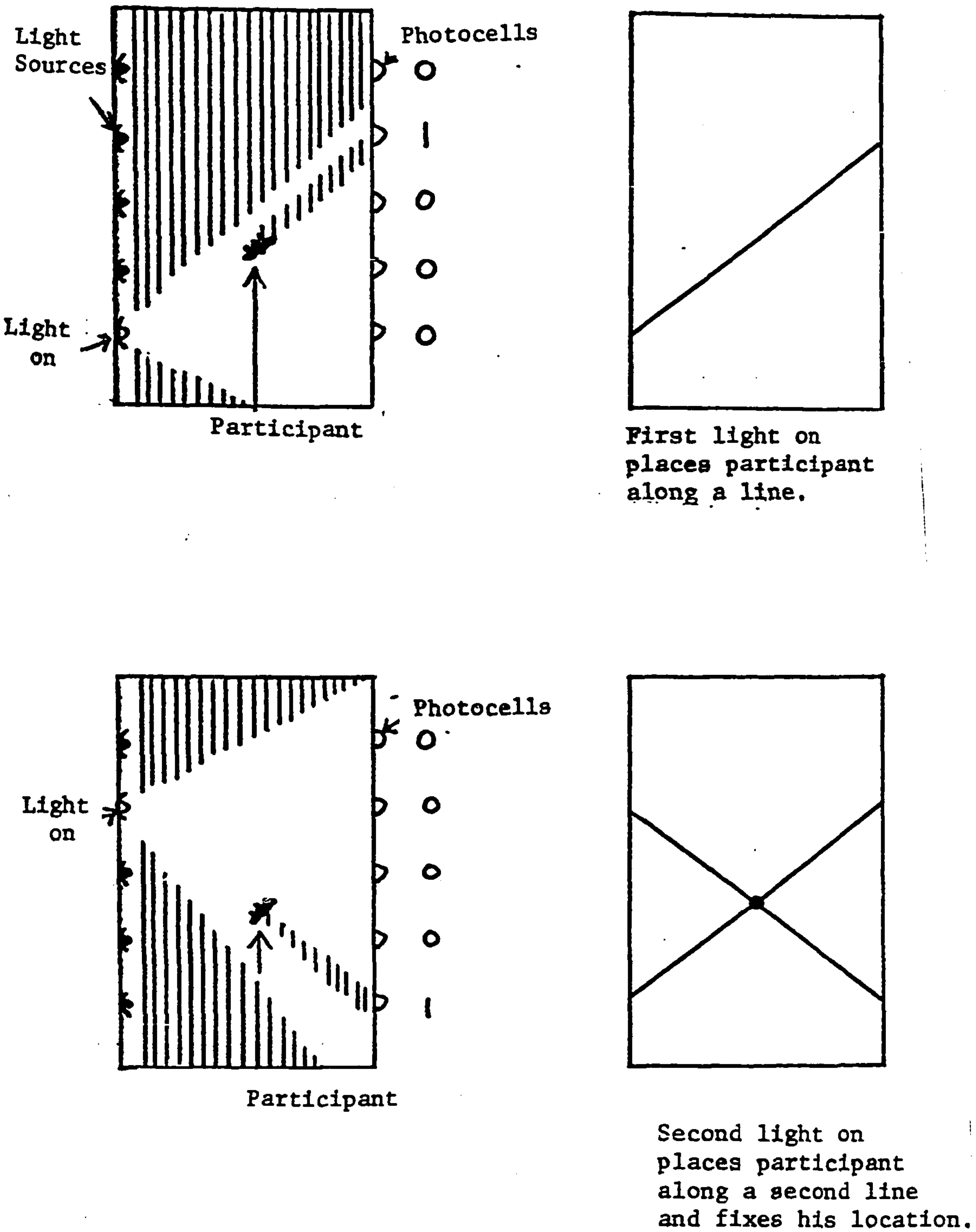
Another method of determining the distance from a given point is to emit a pulse of ultrasonic sound and have it repeated by another transmitter worn by the participant. The time delay from the initial pulse to to the arrival of the echo back at the emitter is a measure of the distance.

6.3.1.3 Occluded Light

Another inexpensive system which is easy to install operates by the occlusion of light by the participants. Distributed around the room are omnidirectional light sources and detectors (figure 6-2). The light sources are turned on one at a time and the sensors then read. Wherever light fails to reach a sensor, it can be assumed to have been blocked by one or more participants who are positioned somewhere along the line joining emitter and sensor. To determine exactly where along this line, another light is turned on and presumably other sensors blocked. This second set of reading should pinpoint the person's location. However, if several people are present the scanning procedure and the computer analysis become more tortured. Such systems probably break down beyond three individuals.

6.3.2 Motion

Motion can be measured directly by using a modified ultrasonic



Light occlusion sensing
fig. 6-2

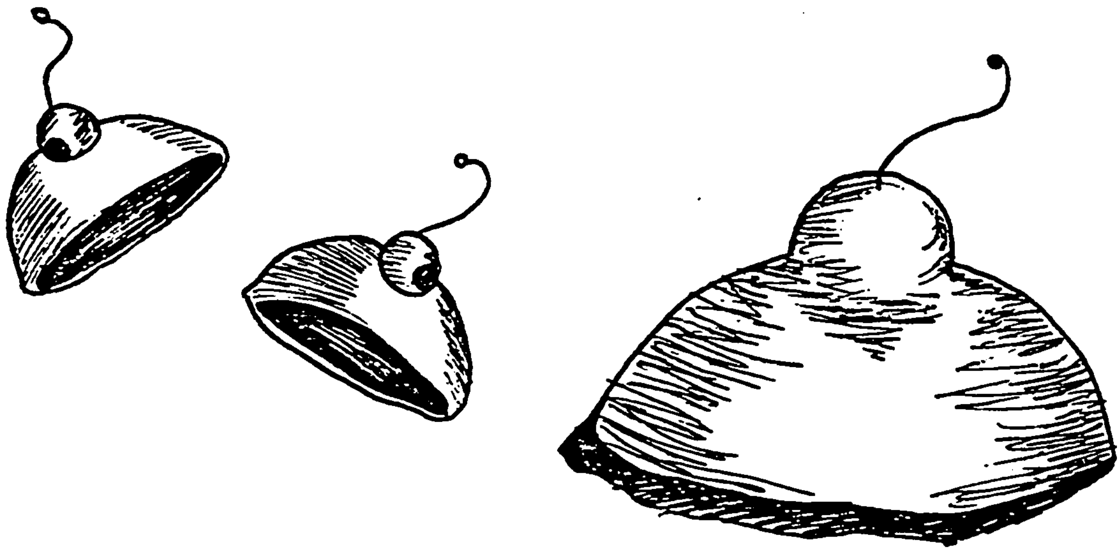
burglar alarm. Motion is reported as a doppler shift from the reflected signal returning to the alarm. The frequency of the doppler signal varies with the velocity of the persons movement and its amplitude with the size of the body part being moved and the distance from the sensor. Multiple emitter sensor pairs can give the velocity component in each of several directions. However this system will be confused if more than one person is present. Also, spurious ultrasonic signals are generated by the jingle of keys and coins in the participant's pockets.

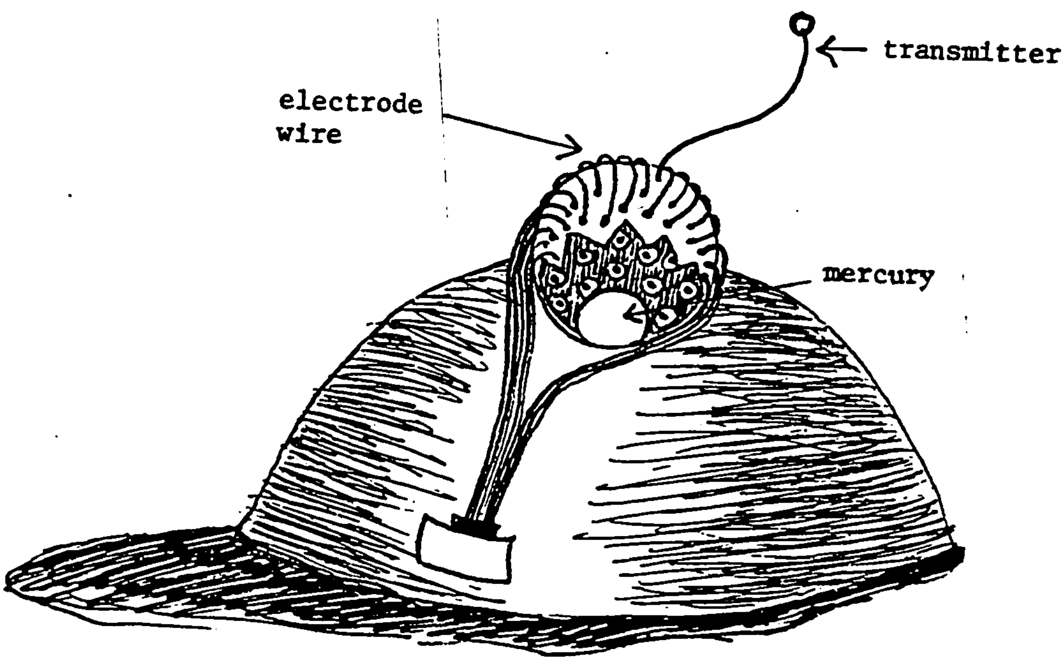
6.3.3 Touch

Any of the methods for sensing position described earlier can be adapted as touch sensors to be placed on walls, ceiling, or on mobile objects within the space. An active sense of touch can be implemented by manipulatable limbs or tentacles on mobile robots or fixed platforms. Another interpretation of this sense will be offered later in the description of image sensing.

6.3.4 Tilt

The angle of the head could be determined by equipping the participant with a cap containing a chamber partially filled with mercury (figure 6-3). As the head tilted the mercury would touch new contacts indicating the direction and degree of tilt. This information would then be transmitted to the computer. The tilt would be extremely useful in an interaction playing with the participant's sense of balance. If the displays define the visual space as in Glowflow, then altering these visual cues in conflict





Mercury Cap

Movement of mercury in chamber indicates the tilt of the participant's head.
fig. 6-3

with the person's own sense of balance (as reported by the tilt sensor) would be extremely disorienting.

6.3.5 Direction Faced

There are also cases where it would be useful to know which direction the participant was facing. This information would allow the computer to generate visual displays that would be visible to only his peripheral vision, (images would move away as he turned his head to look at them). A directional light or radio emitter worn on the participant's head would allow sensors around the room to provide this information. A more elaborate system could monitor his eye glances by reflecting a beam of light off his eyeball. The source, sensor, and a transmitter could be mounted on special eyeglasses.

6.3.6 Image Sensing

Theoretically a tremendous amount of information could be extracted from a video image of the participant as he moved about the space. Most interesting and most easily attainable is the participant's posture, i.e. the disposition of his limbs in the video image. Also available is his position in the room, height, direction faced, and even facial expression. While these last details are readily apparent to the human observer, only the most involved digital processing of the video image can provide them. A number of progressively more ambitious systems will be described along with their strenghs and weaknesses.

6.3.6.1 Photocells

The first system is a grid of photocells faced against a television monitor, which displays the video image of the participant in the environment. Such a system has been used by the PULSA group at Yale and Ted Crainik of the Institude for Advanced Visual Studies at M.I.T. If the output of each photocell is fed into a threshold circuit, scanning the grid of sensors will yield an array of ones and zeroes. By comparing successive readings it would be easy to determine which parts of the image have changed and to respond to those changes. This method is easy to implement and use, but suffers from low resolution and lack of any focussing ability. In particular, if a person in some distance from the camera, his image covers only a small part of the screen and so affects only a few photocells. Any interaction with him must therefore be based on less information than if he were closer.

6.3.6.2 Video Signal Sensors

A second approach is to use the video signal itself and to electronically detect the person's image as the only non-zero part of the image signal. A single threshold detector is used to indicate when the intensity of the picture signal is above zero. By keeping track of which line is being scanned and the position of the beam along the line being scanned when the threshold is crossed, the location of the person's image in the screen can be deduced. In practical terms this requires a counter that keeps track of the line number by advancing with each horizontal synch pulse and zeroing on the vertical synch pulse. Another counter starts with each horizontal synch pulse and advances at a rate several hundred times the 15,000 hertz frequency of the scan. The value of this counter when a threshold is crossed is its horizontal coordinate on the screen.

The next few systems depend on information extracted from these circuits: two counters and a level detector.

6.3.6.2.1 Magic Wand

The simplest system of this type senses a magic wand carried by the participant. The wand is no more than a rod with a light at the end. If the room is dark the wand will appear as the only white spot on a black screen.

The circuitry saves the values of the horizontal and vertical counters when the intensity threshold is crossed (the threshold is only crossed when the white spot is being drawn on the screen). The values of the counters are the coordinates of the wand in the video screen. As the person waves the wand around, the successive coordinates are read into the computer and used as the basis for interactions. Several people could be handled if a color camera was used and each person carried a wand with a different colored light. Of course, a lighted ring or button could be used instead of the wand.

6.3.6.2.2 Outline Detector

The system desribed above can be adapted to provide the outline of the person's image on the video screen. On each scan line the left boundary of his image is the value of the horizontal counter at the first zero-to-one transition of the level detector. The right boundary of his image is the last one-to-zero transition in each horizontal scan. This system does not provide a true outline (figure 6-4). However, it does provide enough information for the participant to communicate with the computer by waving his arms and legs. In addition to his outline this sensor can give some indication of his position in the room. If the camera is at one end of the room, the number of empty scan lines below his image is related to how far away he is. The horizontal coordinate can be figured by averaging the bottom coordinates of his outline while allowing for the the foreshortening effect of the distance. Two such systems mounted on adjacent walls so as to view the participant from perpendicular perspectives would yield most of the information about the posture of his body.

6.3.6.2.3 Color Outlines

By using a color camera and a separate threshold detector for each primary color signal, new possibilities arise--particulary if the participant were to dress in a costume designed to facilitate sensing, e.g. a distinctive color for each body part (figure 6-5). Such a system would provide a tremendous number of clues for interpreting his behavior. Distinctive colors could also be useful in identifying and discriminating different individuals.

The video outline sensor
fig. 6-4

Costume to aid in computer pattern recognition

fig. 6-5

6.3.6.2.4 Signal Sensor Grid

Another approach allows the computer to obtain 16 bits of data on each scan line. Each of these bits indicates whether the average intensity over the sample interval is above a certain threshold. By varying the width of the sample interval and the starting point of the first sample, this system can focus on portions of the screen. It can also vary the threshold level to determine the various gray levels within it. This fine tuning ability would allow the program to home in on smaller and smaller behaviors if the subject were to stand still.

6.3.6.2.5 Advantages and Disadvantages of Video Sensors

These video sensing systems have the advantages noted plus the advantage of portability (all that must be moved is the camera). They also have some ability to focus on parts of the screen. By connecting the camera with motors for zooming, focussing and aiming, these systems could be used as with rough motion detectors or focussed on a small area to allow interpretation of subtle movements of the hand or face. They have a nice aesthetic quality. The participant finds he is manipulating the environment by waving his hands, the traditional gestures of sorcerers and magicians.

There are also disadvantages. Because of the effects of perspective, the image of a person will be smaller when he is away from the camera than when he is closer. More troublesome is the performance of an image system when several people are present. The image of one person can partially occlude that of another making it extremely difficult to resolve them into separate figures. This problem could be alleviated by having several cameras and selecting the one with a clear view or by dressing people in different colors to facilitate discrimination.

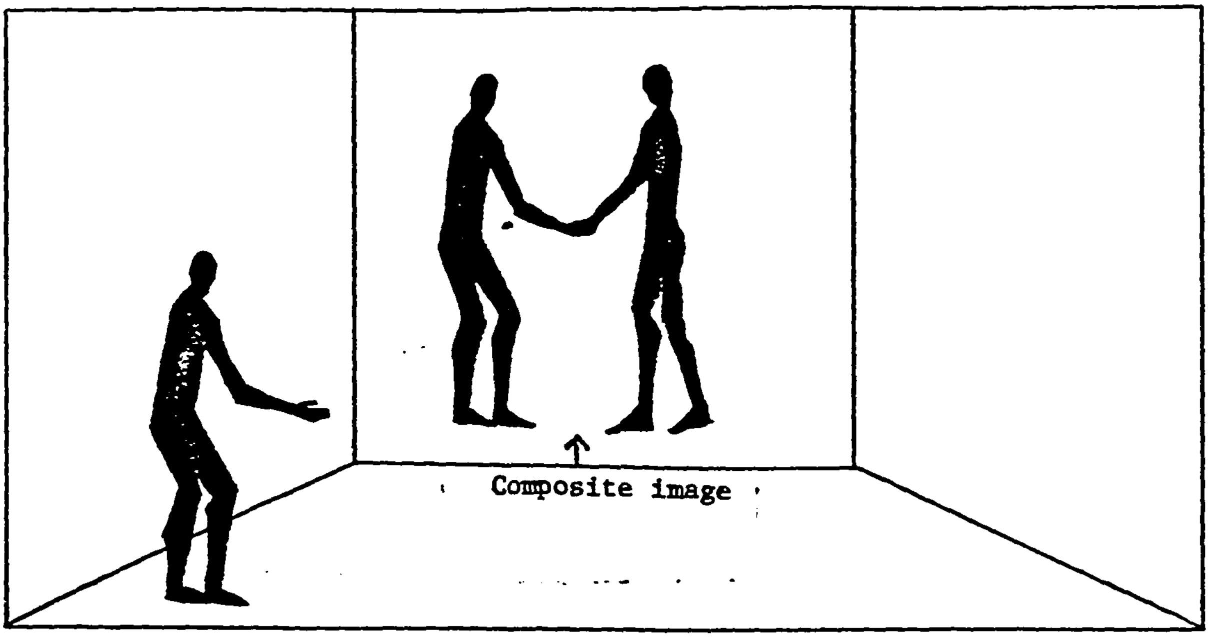
6.3.6.3 Video Touch

The video sensors described above can be used to determine the location of a person in the field of the screen (figure 6-4). Thus the sensor can easily determine whether or not a person is "touching" any particular point on the screen. This ability becomes useful if the video image is superimposed with another video or computer graphic image (figure 6-6). The sensor can then report when and where the two images intersect (touch). This touching of images can be responded to with light or sound, allowing one participant to "feel" another's image with his own.

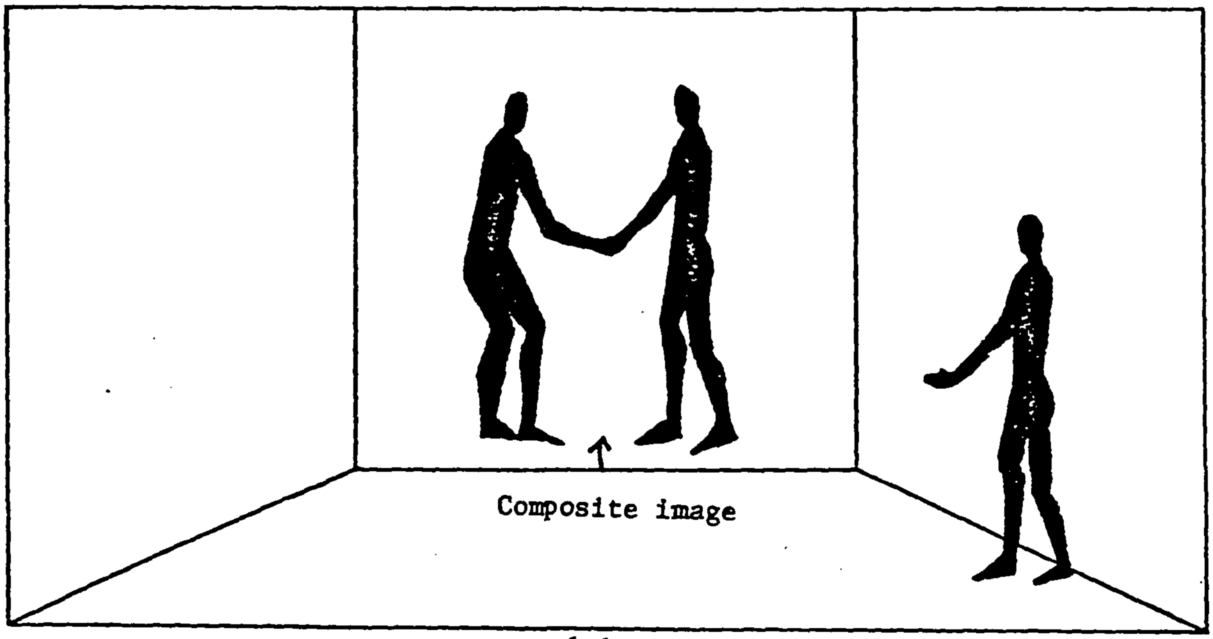
6.3.7 Body Functions

Body functions such as GSR, EDK, EEG, EMG respiration, etc. can be picked up by electrodes attached to the individual. These signals would be quite difficult to control while in physical motion particularly because spurious signals may be generated as artifacts of physical behavior. However, for someone with advanced Yoga or meditation training, physically interacting with an external environment defined by their own internal environment would be interesting. For most people it would be necessary for them to be seated before they could concentrate enough to learn how to control these signals. In this case the interaction might allow them to perceive apparent

Video Touch
Computer detects contact with generated image
fig. 6-6a



Participant X 6-6b



6-6c Participant Y

Video Touch
Computer detects contact between participants images.
fig. 6-6b & 6-6c

movement in the displayed environment in response to their physiological self-manipulation rather than their physical movement.

6.3.8 Sound

There are several aspects of a person's voice that can be perceived and given responses. The easiest is the volume, which can be measured using a peak follower and an analogue to digital converter. Next in importance is the pitch of the voice. The current technique used here is to make a digital count in between successive zero crossings. The result is a digital readout inversely related to frequency, i.e. the higher the count, the lower the frequency. More difficult would be to determine the harmonic content of a person's voice. This would require a series of fixed filters and amplitude detectors. Sensing of more complex sound information such as rhythm or identification of words would require complex pattern recognition programs which currently need more time and larger computers.

6.4 Software

Whatever hardware sensing system is chosen, the data it provides will require further processing by the computer before the act of sensing is completed. Among these computational requirements are the needs to insulate the program from faulty sensors, the translation of the inputs into the format of the interaction, the need to keep track of several individuals, and the need to detect events that are important to the interaction. Most of the examples given will be drawn from experience with the floor system used in Psychic Space, because its idiosyncrasies are best understood by the author. However, any of the other sensing systems described above would have its own computational quirks and special requirements.

6.4.1 Reliability

In Psychic Space the first step in the input processing insulated the program from the (occasionally manifest) possibility that one of the floor switches would become stuck, falsely indicating the presence of a person. To combat this kind of malfunction, the program responded not to the state of the floor but to changes of state. When the floor array was read in, it was compared to the previous reading to yield two new arrays: the first containing only switches that had just turned on and the other containing only those that had just turned off (figure 6-7). These two arrays were then used to selectively set and clear the corresponding bits in yet another array which hopefully mirrored the true state of the floor minus stuch switches. Every few minutes this composite array was zeroed, rendering it again impervious to newly stuck switches. Along the way this procedure isolated the events that were to be of importance to the interaction in the two change arrays. This information allowed the computer to respond to either footsteps or "unfootsteps".

```
o o I I o o o o
o o o I o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o I I o o o o
o o o I o o o o
o o o o o o o o
o o o o o o o I
```

Floor as it is

```
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o I o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
```

New switches on

```
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
I o o o o o o o
o o o o o o o o
o o o o o o o o
```

Old switches off

```
o o I I o o o o
o o o I o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o o o o o o o
o o I I o o o o
o o o I o o o o
o o o o o o o o
o o o o o o o o
```

Virtual floor minus
stuck switches

Floor Sensing
fig. 6-7

6.4.2 Format Translation

Another basic function of the input software is to translate incoming signals in the form of logic levels or duration into the format of the interaction, e.g. positions, velocities. In Psychic Space this conversion was immediate because the 24 x 16 array of floor switches was read into an array of 24 x 16 bit words. A second processing step was required because a person was likely to be standing on several switches at a time. His position could then be determined in a number of ways. In Psychic Space the X and Y values of all switches were averaged. However, the position could have been associated with the most recent event. In any of the triangulation systems described earlier a significant amount of computation is required to translate the input signals to an X-Y coordinate representation. This could be avoided by using a polar coordinate system.

6.4.3 Multiple People

Given the presence of a number of people the inputing program is called upon to separate the input signals into distinct individuals and to assign the most likely identity to each based on his prior location. Currently, the programs base their decisions on the distances separating these inputs from the previous locations of identified individuals. The distances can be recorded and responded to if desired.

6.4.4 Ambiguity

If the separating distance is too small to isolate the individuals with certainty, the sensing program can report the ambiguity as an aesthetic event which the controlling program can recognize with a distinctive response. The ambiguity can become ignorance in several cases. With the floor sensor the participant can disappear by jumping or climbing on another person. With a video sensor he can hide behind someone else. Alternately, one person may appear as two on the sensing floor. By lying down he will close switches far enough apart for the resolving program to conclude that there are two people.

6.4.5 Software Sensing

In some interactions the computer must interpret the participant's behavior in terms of an internal model of the environment that it is displaying. In Psychic Space the computer viewed movements on the floor as movements in a maze. Each step had to be tested against the model of the maze to make sure the participant had not crossed one of its boundaries. In more advanced systems there will be interaction with a completely displayed world varying with the participant's apparent movement within it.

6.5 Conclusion

One final but crucial observation about these perceptual systems is: they will all fail. Each can be fooled in certain cases. However, their goal is not necessarily to perfectly report events as they occur. Rather they are to represent the act of perception itself, and to suggest by their strengths and weaknesses just how selective the perception of any creature must indeed be.

CHAPTER 7

RESPONSIVE OUTPUTS

7.1 Introduction

Since the computer must respond to the participant, it is appropriate to consider the various means it might use to do so. The initial discussion defines the functions and requirements of any responsive display. Later, displays designed to stimulate each of the human sense modalities will be described. Light and sound displays will receive the greatest attention, since these senses are the best understood and have the greatest capacity for receiving information. Displays are suggested which exploit the expectations of these senses based our life long experience in the physical world and shaped by centuries of aesthetic tradition. The effects of hardware decisions on the interactions are mentioned throughout the chapter.

7.2 Aesthetic Issues

7.2.1 Functions of the Displays

7.2.1.1 Feedback

The function of the real-time outputs is to display the computer's response to the participant's behavior. Consecutive responses establish relationships between what the participant does and what he perceives as well as expectations about the consequences of future actions. Each response then is either a further verification of the current relationship or a signal that the old rules no longer apply.

7.2.1.2 Context for Interaction

In addition to providing direct feedback to the participant's behavior, the displays may also define the context within which the interaction appears to be taking place. The only example to date was in Psychic Space where the Maze was projected as the participant walked around it. In future environments the computer may create visual domains of such effectiveness that the participant will feel that he is existing in the displayed space.

7.2.1.3 Representation of Behaving Entities

Another use of the displays may be to define behaving entities, artificial creatures which interact with the participant or a representation of him in their display space. Although robots are typically thought of as physically realized, mobile creatures, they can be quite convincingly represented on a visual display. Less successful, but still possible, is the use of the sound alone to accomplish the same result.

7.2.1.4 Manipulation of Participant's Behavior

Feedback is also used to encourage behavior in general, and desired behavior specifically. In the environment where nothing happens unless the participant moves, each response is a reinforcer which promotes further activity. Similarly, when a lower level of activity is desired, it can be brought about by ceasing to respond, delaying response, or responding only after progressively longer delays. Just as a painter has techniques which guide the observer's eye to important parts of a picture, the environmental artist will sometimes wish to provoke very specific actions such as moving to the starting point of the Maze in Psychic Space. In that darkened environment it was very easy to suggest the desired action by displaying an unexplained symbol at the starting point. The participant invariably wondered what would happen if he moved his symbol there. When he did, the unknown symbol disappeared and the Maze appeared around him.

Using sound alone such guidance is possible but slower and less sure. If the environment only responds to movements in a certain direction, the participant usually tends to move in the favored direction.

7.2.1.5 Identification of Individual Participants

The response can also be used to define an identity for each participant if several are present. Only if each person's response is completely different will he be able to know that the environment is responding to him and not to someone else. If the relationship changes or is exchanged for someone else's, the participant must then discover his new identity.

7.2.2 Requirements for Displays

7.2.2.1 Computer Compatibility

There are a number of requirements which must be satisfied by any display. At the very least it must be amenable to computer control and designed to take advantage of the computer's capabilities. It must respond at computer speeds and have a large vocabulary of possible responses. The tubes in Glowflow failed by both of these criteria because the phosphors were slow to respond and the number of patterns severely limited by the arrangement of the tubes. It is economical if a display is general enough to express a large number of relationships around different themes, since it is then a tool for exploring a whole domain rather than a single piece.

7.2.2.2 Environmental Scale

To encourage the participant to use the space is helpful if the displays also use the whole space. For instance, visual displays should be large enough, to give the feeling that they are the space rather than only small objects within it. The tubes in Glowflow were completely successful by this criterion, while the video projections of Metaplay and Psychic Space were less so, because images and therefore the interaction were focussed toward one end of the room. However, the projection screen was large enough so it became the end of the room. Still, it would have been preferable to have rear-view projection on all walls.

With sound the environmental criterion still applies, mandating a sound system which involves a number of selectable speakers thus allowing the origin of sound responses to move around the room.

7.2.2.3 Total Control of all Sensation

Since the conditions for display are as important as the display itself, it may be necessary to control the space completely so that the display is the only source of stimulation. In this way visual displays are contrasted with darkness and sounds with silence. Against this background of sensory deprivation the displays not only appear more dramatic but their stimulation is necessary for the participant's psychological comfort.

7.2.3 Complexity of Feedback

7.2.3.1 Complexity of Experience

One point which should be emphasized is that complexity is a central issue in this medium. Clearly, the displays and the relationships they define must be complex enough to be interesting. However, the participant must attend to the following:

1. Processing the environment's most recent response,
2. Interpreting the relationship indicated by that response,

3. Choosing his next action,

4. Predicting its consequences, and

5. Effecting that action.

Therefore the light and sound information need not be as complex as they are in the passive art forms, where the audience just watches or listens.

In fact, there is definite danger of a sensory overload with the person unable to understand all that is happening. In other media and especially in what is called "intermedia," the idea of overload is in vogue. Partly this may reflect a boredom with conventional media and frustration with their inability to surprise. Within this environment it is simple to surprise. The problem is rather to provide enough structure to define the relations which when broken create information.

In the beginning we have to introduce the whole idea of composed response, to patiently define relations, and only when they are apprehended begin to play with the framework of the medium. In a mature medium it is necessary to break the rules of informed expectation in order to communicate. On the other hand the rules must be there to be broken or the possibility for information does not exist. Our first task then is to define the initial rules.

7.2.3.2 Argument Against Representing the Real World

One tendency which is not necessarily desirable is the use of displays to reproduce the real world. The technical evolution of television suggests that other displays will undoubtedly progress toward continually greater realism. But it is probably an error to try to guide aesthetic displays in this direction, particulary since one of the themes underlying this thesis is that our perception of the physical world and the reality we design for ourselves are ultimately arbitrary. Also, from an aesthetic point of view the surreal quality of projected computer graphics may be more effective than a completely faithful rendering of a real environment. What is important is that the displayed space appear sufficiently compelling for the participant to suspend belief and accept the experience it offers as real even if the world it tries to portray is not.

There are, of course, more practical reasons for postponing representationalism, i.e. computers currently are completely incapable of generating realistic displays in real-time. Line drawings and somewhat arbitrary sounds are the best that can be expected at the moment, although video graphics can be expected in the next few years.

7.2.3.3 Displays need not be Art

Another criterion that is denied rather than affirmed would require that the displays by themselves be works of Art. The displays here do no more than provide a means of communicating relationships between the participant's behavior and the environment's response--to do more would distract, particularly given the current tendency of people to sit down and watch, whenever they face an effective display. Furthermore this medium is based on participation, whereas detachment and uninvolvement have been suggested as necessary criteria for judging work of Arts.[1] It is known that images and sounds can be composed to produce Art. What is unknown and remains to be tested is the validity of an illusory medium where the laws of Nature are replaced with our own composed alternatives.

7.3 Output Modes

Displays for communicating with each of the human senses will be discussed below in some detail. For vision and hearing the expectations based on our experience in the physical world or exposure to our art forms are well understood and will be described before considering the hardware. For each sense the existing methods of display will be tested against the functional criteria stated earlier; most will fail, at least partially. Modifications of the existing hardware are suggested and entirely new approaches developed which are more suitable to computer control. Throughout this discussion the effect of hardware decisions on the interaction will be noted, especially where a particular configuration suggests a specific interaction.

7.3.1 Visual Expectations

The most important and best understood sense is vision, which, more than any other provides us with our sense of place. When visual data conflicts with that of other senses it usually dominates. Partly this dominance is the result of very simple expectations which are met in the right-angled world created by Western Man. The following example is from the author's personal experience and is offered to indicate the aesthetic importance of these conventions and to motivate further discussion of them.

7.3.1.1 Mystery Ride Example

Several years ago on the Boardwalk at Ocean City, New Jersey, the author went through a concession called the Mystery Ride. A group of about ten people entered a very ordinary seeming room complete with pictures on the walls, a light fixture hanging from the ceiling, and a rug on the floor. We were seated on two benches that were suspended by heavy beams from either end of the room. When the ride began, it seemed we were being turned upside down. This was alarming because there were no physical restraints to hold us onto the bench. After a panicky moment, the author reasoned that it was the room that was turning around the participant's and not the other way around. Unfortunately, this intelligence was not at all reassuring, for years of experience tell us that ceilings are up, and floors are down, and when one finds his head by the floor and his feet by the ceiling, he can usually assume that he is upside down.

The author closed his eyes to rely on vestibular sense. The semi-circular canals which had served to make him sea-sick in the past were now being asked to offer evidence in support of intellect in its case against untrustworthy vision. Unfortunately, the authority of the visual interpretation made the interior sense unreadable. While the author was familar with the psychological literature describing visual illusions, he had never guessed how dramatically vision was able to tyrannize the other senses and overrule reason as well.

This illusion suggests that there are a number of conventions established by our visual experience which can be exploited for use in an environmental display. More than the other senses, vision defines reality or unreality and can be used to establish an abstract space containing entities and objects. It can suggest an apparently familiar environment and based on that disorient and unbalance by changing what is perceived or its expected relationship to one's behavior.

7.3.1.2 Continuous Feedback

Some of these visual expectations are the result of the consistent experience that accompanies movement in any physical space. As we turn our head or move around, we are accustomed to seeing one perception transformed into the next in very smooth and connected way. The visual feedback could deviate from this expectation in a number of ways. First, a person's movement in one space might result in his moving about another in a disconnected way. The rate of movement could be exaggerated so that a normal three-foot stride in one space would result in an apparent thirty foot change in position in the other. If this relationship were maintained for movements in the other directions, we would have an amplifier of visual position. Thus, by physically moving around this small space, a person could explore a much larger one perceptually.

7.3.1.3 Perspective

In addition to continuous feedback, we expect that when we approach an object it will become larger, and when we move away from it, it will become smaller as it fades into the distance. This relationship could be reversed, so that as you moved toward a displayed scene, it would appear to recede, whereas, if you were to reverse your direction, it would become larger. This suggest a whole family of such translations of the physical space into a perceptual space. By moving in one direction a person might cause the perceptive environment to rotate around him rather than to approach and recede. Not only could the individual seem to move about a much different sort of space, but the space could also be perceived to move about the individual.

7.3.1.4 Vision and Memory

Since vision expects continuity, it relies less on memory than the other senses. As we move around the physical environment, we don't have to remember what we saw a moment before, it's either still there or something derived from it remains. Sounds, on the other hand are heard and then cease to exist; they must be remembered as they are interpreted. Perhaps for this reason there is no tradition of composing sequences of abstract visual sensation as there is for sound, although the films of John Whitney suggest that such an art form could be possible and effective.

7.3.2 Visual Displays

Many familiar displays such as slides and film must be ruled out because they are inflexible or not suitable for computer control. Others, such as discrete lights, may be eminently computer compatible but lack the ability to suggest very interesting ideas. Most promising are the real-time imaging capabilities of television and computer graphics. But even these systems require extensive modification before their potential is realized. Examples of these approaches will now be considered in greater detail.

7.3.2.1 Discrete Lights

Arrays of lights are perfectly suitable for computer control if they respond fast enough. The lights activating the tubes in Glowflow were all under independent computer control. The strobes used in Glowmotion and by the PULSA group are also examples of discrete light displays.

7.3.2.1.1 Space Dance

The distortion of space accomplished in Glowflow could be extended by using a large number of linear light sources such as extremely narrow fluorescent tubes or electroluminescent strips to define a number of alternative visual spaces. Each subset of the lines would define a particular illusory space within the darkened environment. By switching different groups of lines on or off the space itself would be articulated and could seem to move around the participant. While such an environment would be very exciting and well worth doing, it is limited to the single theme of spatial distortion.

7.3.2.1.2 Graphic Floor

Another plan is to build a 64 x 96 array of discrete lights into the floor. Either LED's or neon bulbs might be used. Such a display would be extremely powerful because it would bring the responses close to the participant, making an interaction like the Maze more immediate. The tremendous number of lights makes a rough approximation of CRT graphic capabilities possible. While the 3" resolution still limits the detail in any pattern, a tremendous number of interactions would be possible with such a display.

7.3.2.2 Computer-Video Integration

The ensuing discussion considers two real-time display systems: computer graphics and live video. The existing equipment that defines each medium will be described first. Then, extensions are suggested which will make each medium more suitable for use with the responsive medium. Finally, a merger of the two now independent approaches will be attempted.

7.3.2.1.2 Computer Graphics

The best real-time computer output system today is the graphic display computer capable of generating simple drawings of several thousand lines in real-time. In most machines, such as the Adage used in Metaplay and Psychic Space, the system is capable of drawing point to point vectors, although with the Conographic Display,[2] lines are based on curves rather than straight lines. The more powerful systems allow an image to be moved, scaled and rotated in two or three dimensions automatically by the hardware. While the computer can generate complex images, the limits of its computational power becomes evident all to quickly as one attempts to modify such images dynamically. However, if a space is displayed and projected, even a simple set of lines can be quite compelling as one seems to move around the space by moving around the room. As stressed earlier the emphasis is on the relationship of the participant to the environment. The processing limitations of the computer enforce this focus. It is simply impossible to create truly complex programmable displays with current technology.

Line drawings obviously represent a very limited medium of expression. The computer can do better using systems which shade in the surfaces on the images of solid objects. Additional processing smoothes these surfaces yielding convincing representations of three dimensional solids. Synthevision, a commercially available system, provides this service, but is far from performing in real-time. Until a breakthrough occurs in this area, real-time computer graphics will be limited to sketching objects with lines.[3]

7.3.2.2.2 Real-time Video Medium

While everyone is familiar with video as a broadcast medium, its possibilities for real-time interaction are largely unexplored. An occasional closed circuit video mirror in which an individual sees himself looking at himself, perhaps with delayed feedback, seems to be the limit of current imagination. In fact recent interest in video synthesizers has been to use them as a means of generating kinetic images to be recorded on video tape. The use of these new visual techniques with live images has not been considered as seriously as it should for video is fundamentally a live medium. The following paragraphs describe the current hardware and then suggest changes that would make video more controllable.

7.3.2.2.2.1 Video Synthesizer

One of the new methods of generating abstract images pioneered by Nam June Paik is to use electronic function generators to create visual patterns which are unrelated to any camera input—the visual analogue of the MOOG sound synthesizer. Like the MOOG it suffers from the following paradox: while there seem to be an infinite number of possibilities, the resulting output suffers from a certain simplicity and lack of control. This problem will crop up over and over with all the displays but it is particulary acute where a computer or electronic circuitry (in fact, an analogue computer) is the sole source of complexity.

7.3.2.2.2 Visual Image Processor

One solution is to use real images as a source of complexity. Parts of several different images can be merged according to fairly simple electronic rules to form composite images. The basic processing is based on detecting intensity thresholds or abrupt changes in levels indicating boundaries in the images. While one of these conditions is satisfied, the processor will replace one image with another or parts of another in the scan, or one color or intensity level with another. Such devices have been designed by Paik and Dan Sandin at the Chicago Circle campus of the University of Illinois.

7.3.2.2.2.3 Video Feedback

Another aspect of video image processing is feedback in which the monitor image is picked up by the camera driving it. In the simplest case the result is the progressively smaller repetition of the image within itself. As the angle of the camera is varied and the full capabilities of processing added, beautiful dynamic imagery can be achieved. The problem with feedback is the lack of control; pretty images are easy, almost automatic, but to truly conceive and compose is next to impossible with most equipment. Thus, as one observer commented, "Feedback is a whore," since it distracts from more serious pursuits. However, there are approaches which may make feedback and image processing more plastic and composable.

7.3.2.2.2.4 Plastic Video

With most available equipment video is an extremely rigid medium. Images can be processed together but only if they are synchronized. Then any given point in the resultant image corresponds to the same point in one of the input images. For video to truly become an artistic medium, it is necessary for the image to be more malleable, more subject to the will and whim of the artist, more plastic.

The most oppressive constraint is the tyranny of the raster scan. By overcoming the linear scan it is relatively simple to distort the image. All that is required is to put the video image on the screen of an X-Y oscilloscope using two external sawtooth generators to generate the raster, one at 60 hz and the other at 15750 hz, both synchronized with the synch pulse in the video signal. When this has been done it is obvious that the X-Y deflection signal would by any set of waveforms at all, with each waveform producing its own distortion of the original image. If these waveforms are made contingent on the input image even further freedom results. Bill Etra of NYU has designed an image processor incorporating some of these concepts.

If the oscilloscope could have several independent electron beams each with their own deflection signals, we would have a far less limited way of combining images since several images could be handled simultaneously without synchronizing their scans. The input of such a device would be one or more standard images entering in parallel. Arbitrary raster signals would then be added to control the placement of the images, allowing both continuous and abrupt deformation of any video image. Sub-images could be selected, and expanded, shrunk, or oriented in any way. The ability to create a collage of such images would require a complete rethinking of what video is, particularly if a means can be found to project the composite image without converting it back to a raster scan. Clearly the tool described would bring both new freedom and control to video feedback work. Variations based on the scale and the interaction of scanning rates and angles would be unlimited and yet subject to fine control. At some point the processing may be accomplished within the computer, but that day is still far off.

7.3.2.2.3 Computer Controlled Video

The interface between computer and television is complicated by the fact that television operates at a considerably higher data rate than the computer. The simplest control is where the computer selects one of several video images. This selection can be done rapidly giving the live equivalent of the fast frame techniques familiar in film. It would also be possible to imitiate the children's books that place the top half of one illustration with the bottom half of another. Or, by switching within each horizontal and vertical scan, a mosaic of a large number of image parts could be created.

The next step would be to use the computer to control one of the image processing devices described earlier. The interfacing problems are similar to those to be solved when interfacing electronic sound synthesizers. Both will be discussed later in this chapter.

Another step is to use the computer to generate graphic images which are converted to video and then used as part of familiar video techniques. When a simple computer image is scanned by video it appears as an abrupt transition from dark to light and back, which could be used to control the processing of two live images without appearing in the output itself. This computer image can be changed dynamically, providing a moving geometric window from one live scene into another.

7.3.2.2.4 Computer-video Merger

Both video and computer graphics share a common means of display: a cathode ray tube where the image is the result of phophorescence excited by a beam of electrons. In computer graphics a beam of constant intensity is directed from one arbitrary point along the screen to another, whereas with video the path of the beam is fixed by the raster and the intensity is continuously variable. The modifications of video suggested above actually create a new electron beam medium in which traditional video and computer graphics are but special cases of a more general phenomenon. All that is needed is graphic hardware where both the beam intensity and its path are subject to continuous modulation. Also desirable would be the presence of several independent electron guns and a means of projecting the image directly without converting it back to a raster scan.

A combined system would accept a number of standard video inputs each of which would go through a scan conversion tube capable of detecting the outline of the participant's image. The output scan from this device could orient his image anywhere in the output frame. The picture plane in which the video image lay could then be rotated in a third dimension calling attention to the fact that video is traditionally a 2-D medium. Computer generated images could then, for example, walk on this picture plane or walk off with the participant's head, kicking it like a ball. With current computing power it would probably be impossible to keep track of a body part like a head in real-time, especially if the participant raises his arms or covers his face; however a storage scope could hold a single frame image while it is manipulated. This device also allows the image to be replicated around the screen. The live images can be digitized and transformed into computer images which outline the real ones following them around until some point where the computer image goes off on its own.

7.3.2.3 Holography

Holograms cannot be considered for real-time interaction at the moment, but their very desirable qualities will undoubtably lead them to be under computer control in the future. The advantage of the hologram is, of course, that it gives a three-dimensional image. Even more important, a projection hologram creates a free standing image in mid-aid, instead of associated with a screen or surface. For the moment the following disadvantages outweigh the advantages. Holograms are mainly a static photographic medium, although there is experimental work on moving film images and inadequate real-time displays have been produced by acoustic holography. Most important is the fact that there is no real-time method of defining arbitrary holographic images and thus no way of using the computer to control or generate holograms.

7.3.2 Auditory Expectation and Displays

7.3.2.1 General Discussion

The conventions of everyday auditory experience are quite different from those of vision as sounds are less responsible for determining our sense of place. A given sound may be associated with a certain environment; but, if the visual information conflicts, suggesting we are somewhere else, the sounds will be overruled and the visual interpretation will dominate. Perhaps, this is because radio and phonographs constantly bring us sounds unrelated to our physical environment. While television, photographs, and films do this visually, these sources are directional (they must be faced) and exist as clearly defined, bounded objects within the space (unlike sounds which become disassociated from their origins). Sounds also start and stop, accompanying dynamic phenomena but having no static existence of their own.

Auditory expectations based on physical experience are thus less pronounced and auditory illusions which while some are known to exist, are more subtle and less dramatic. At the same time the computer is relatively unable to faithfully synthesize real-world sounds or to suggest them as well as the graphic display can sketch real objects. However, there is a well-defined tradition of abstract sound sequences, i.e. music. While it is not necessary that the environment produce music, these musical expectations can be used in varying the sound feedback. After a pattern of responses has been established, it becomes expected. Subsequent responses can deviate just enough to surprise but not so much that the participant ceases to wonder what the result of his next action will be. The participant should have a sense of what the response ought to be. His predictions should be right often enough that he trusts the orderliness of the environment but wrong often enough that he is never absolutely certain that the response he expects will occur.

7.3.2.1.1 Manipulation by Sound

Since we rely less on sound for orientation, we are less susceptible to manipulation by sound alone. Sound can be used to reinforce desired behavior, but this process is much slower than the instant visual suggestion used in the Maze. However, there are very effective techniques for accomplishing more general changes within the participant. Since movie sound tracks are used to set moods and to enhance the emotional impact of visual events, it should be possible to communicate feelings of suspense, foreboding, or merriment using the same musically simple techniques.

7.3.2.2 Sound Hardware

The requirements for immediate computer controlled response dictate the use of some kind of electronic sound synthesizer. Recorded or live sounds are possibilities but since they are less versatile, they will be discussed last.

7.3.2.3.1 Electronic Synthesizer

Electronic synthesizers like the MOOG, ARP, and Putney are in fact analogue computers designed to produce very complex waveforms. They typically consist of a number of discrete processing modules under voltage control: e.g. oscillators (VCO's) filters (VCF's), amplifiers (VCA's), envelope generators, sample and hold circuitry, and ring modulators. The output of each device can be fed into either the singal or control inputs of another. At first the number of possible signal paths would seem endless and therefore the sound completely flexible. However, these instruments produce a large class of sounds electronically derivable from four very simple waveforms: sine, sawtooth, triangle and pulse. Because these sounds generated by implacably precise electronic means rather than more sloppy natural methods, they tend to be fatiguing if listened to for any length of time. Furthermore, the MOOG and the other synthesizers are almost incapable of live performance. Most of the recordings of electronic music are the result of a series of tape overlays and not a single taping because changing the timbre of the sound requires changes in the physical wiring, taking seconds to effect.

7.3.2.2.2 Computer Controlled Sound

7.3.2.2.2.1 Waveform Generation by Computer

The computer can generate sounds itself by driving a digital-to-analogue converter (DAC) directly. Of course, just outputting the 40,000 values per second required to produce undistorted sound leaves the computer very little time for deciding what sound to produce next. It seems desirable then to delegate the actual generation of sounds to some kind of external waveform generator.

7.3.2.2.2.2 Synthesizer Control

Perhaps the simplest approach would be to use the computer to control an existing synthesizer. With any given set of connections the computer could provide control voltages to the various modules via DAC's. To gain the full power of the synthesizer it is necessary to find an electronic substitute for the physical patching done on the standard synthesizers. The first problem is that abrupt switching of audio signals can introduce a popping sound unless it is done at a zero crossing. The second is that, if there are N discrete processing modules in the synthesizer, there are in excess of N! different patches. The number is even larger because some modules have multiple signal and control inputs.

7.3.2.2.2.3 Frequency Multipleing

One solution might be to use a single wire as a signal bus by using frequency multiplexing. The frequency spectrum of the wire is then divided into as many bands as there are device outputs. The output of each device would then be converted into an amplitude modulated carrier signal. Any other devices on the bus could then tune in on that frequency for its input. Of course, the requirement that each input be equipped with a variable demodulator may seem extravagant, but in view of the declining costs of electronics, it may become practical. Notice that such an approach would be also suitable for use in a video synthesizer. Such multiplexing techniques are common in long distance communications but have not been considered for communication within a single piece of equipment. Any other approach means settling for a small subset of all possible connections and losing much of the instrument's power.

7.3.2.2.2.4 External Waveform Generators

As mentioned earlier the synthesizers are typically limited to four very simple waveforms as the basis for synthesis. The computer could output a series of digital values describing one period of a more complex wave to an external generator which would then draw the wave repeatedly at a rate governed by one of the digital values. The generator would be an X-T (time) vector generator instead of the familiar X-Y vector generators used in graphic displays. The waveform would be described by a number of paired values. The first would be the slope the wave is to take from its current value and the second the number of clock cycles it is to continue at this rate of change. The waveforms generated by such a scheme are still simple, but represent a considerable improvement over those of the MOOG, especially since these waveforms can be subjected to all of the other functions in the synthesizer.

7.3.2.2.5 Fourier Synthesis

The problem with both computer music and electronic synthesizers is that they are geared to generating waveforms as a whole whereas the human ear hears them only as the sum of their constituent harmonics. (The Fourier theorem states that any waveform can be thought of as the sum of harmonic sine waves. A waveform is said to be in harmonic relation with another if its frequency is an integral multiple of the other, which is called the fundamental). Joe Pavlat, an undergraduate at Wisconsin, has been working on a computer program for generating sounds and music by Fourier synthesis. The problem is that this system requires hours of processing for each minute of sound.

7.3.2.2.2.6 Fourier Hardware

A possible solution would be to use a parallel processing approach designed just for this one application. Since sound would be viewed as the sum of harmonic waveforms there would be a separate processor for each harmonic. Each processor would generate a sine wave at a frequency which was an integral multiple of the clock frequency which would represent the fundamental. The sine wave generation could be done by any suitable method, e.g. a Read only Memory with a sine table read into a DAC. These separate processors would be interconnected so that a change in the fundamental clock frequency would automatically cause all the separate processors to maintain their harmonic relation to the new fundamental. An added fillip would be to allow each processor to detune around the expected harmonic; the outputs of each processor would go through a VCA under computer control through a DAC. Thus, the main computer would control the amplitude of each of the harmonics from moment to moment. It is the attack and decay characteristics of the different harmonics that give physical instruments their distinctive sounds and can similarly be expected to define the interesting dimensions of electronic sound.

7.3.2.2.2.7 Speech Synthesis

A development of interest is the introduction of an economical (under $4,000) speech synthesizer (by Federal Screw Works) which allows the computer to utter phonemes. Its use for generating explicit English statements is probably too obvious to be aesthetic. But the idea of words as the consequence of footsteps or hand waving does present interesting possibilities.

7.3.2.2.3 Real Sounds

The use of realistic, live or recorded sound is limited in general but of interest in a few special cases. It may be desirable for the computer to have a vast repertoire of real sounds that it can call up at a moment's notice. However, there is no such enormous random access system available.

More feasible, but less interesting, would be to select a response from a number of continuously running tapes or live sound sources. If the selection were varied rapidly the result would be collage of sound. The alternative sounds could also come from each individual musician in a group whose instruments produced only inaudible electronic signals which the others could hear through earphones. The participant could just select one at a time. Only by moving quickly would it be possible to get an idea about the music as a whole. Of course, the musicians need not be in the same space.

Another example would be to encourage the participant to speak or yell by responding to noise. If these sounds were then recorded on several different tape loops, they could again be played back on a selected fragmentary basis. Finally, movement around the darkened environment could be used to make a live auditory exploration of another public place. Numerous concealed microphones or a single shotgun mike could be controlled so as to allow selective eaves-dropping in the other place as the participant moved around the environment. The relative positions of the various conversations would be preserved but all visual information would be lost.

7.3.2.2.4 Sound Position

Another dimension was explored in Glowflow, i.e., changing the origin of the sounds by switching amoung a number of speakers so the sounds move around the room or bounce from wall to wall. When these speakers have different signals at different amplitudes the result can be a texture of sound evoking thoughts of wind and rustling leaves. Selecting speakers is also useful when several people are present so each person's sound response follows him around the room physically.

7.3.3 Tactile Displays

The sense of touch is not as easily addressed because there is no electronic way of projecting its stimuli. On the other hand, if the participant were to wear a suit containing a number of electrode stimulators, effective results might be achieved. Similar arrangements have been used to bring rough visual images to the blind and new research is uncovering tactile illusions which make such stimulation promising. These electrically induced sensations could be used in coordination with a sensing system that reported the position of the person's body. For instance, if a holographic object were projected, electrical stimulation of the hand which coincided with its intersection with this projection would be interpreted as the feel of the object. As mentioned in the last chapter the sensation of touch can also be communicated audibly. If when your image touches another image, you hear a sound, that sound becomes the feel of the other image.

7.3.4 The Display of Taste, Smell and Balance Sensations

The remaining senses are difficult to reach by computer controlled displays. Consequently, they are rather unimportant in this medium and will be dealt with only briefly here. By itself, taste is extremely limited and is seldom associated with any behavior other than eating. Smell is difficult to deal with because of the physical behavior of odor causing chemicals. Odors move through the air slowly and linger for some time so a wind tunnel would be required to allow rapid delivery and evacuation of smells. The sense of balance and momentum can probably be stimulated visually as suggested by the Mystery Ride Example. All of these senses, together with the Kinesthetic sense, are probably best left out of the environment until they can be dealt with more effectively.

7.3.5 Electrode Stimulation of the Brain

The ultimate display may bypass the sensory receptors and go directly to the brain. Recent experiments with blind people have demonstrated the feasibility of introducing coherent visual information directly to the brain.[4] If a similar capability were added for the other senses a total synaesthesia could occur. Smell sensations might arrive in stoccato fashion, in counterpoint to tastes and sounds. Such possibilities are exciting and frightening. The courage to take this step will undoubtably be found first by those handicapped by the physical loss of these senses.

7.4 Conclusion

While the preceding discussion indicates a bewildering number of possible responsive displays, it also suggests that effort should be concentrated on the development of unified computer-video medium enhanced with electronic sounds. While still limited, such a response capability would be more than able to swamp the information processing capacity of the participant as he moves around the space, particularly if the responsive relationships keep changing.

CHAPTER 8

PROGRAMMING

8.1 General

This chapter will consider the programs required to operate responsive environments. Since most of the shows have been controlled by minicomputers, the programming to date has been necessarily simple. As larger machines become available for this work, more sophisticated use of the computer will be possible. At that time it will become appropriate to define a language for composing and controlling these experiences. Until then the software must focus on the interpretation of the inputs, the generation of the outputs, and the scheduling of these computations. Only after the input and output hardware and software are fully developed will the composition software become the highest priority. At that point a meta language using net structures will be created to assist the artist in defining the conditions and processes he considers important.

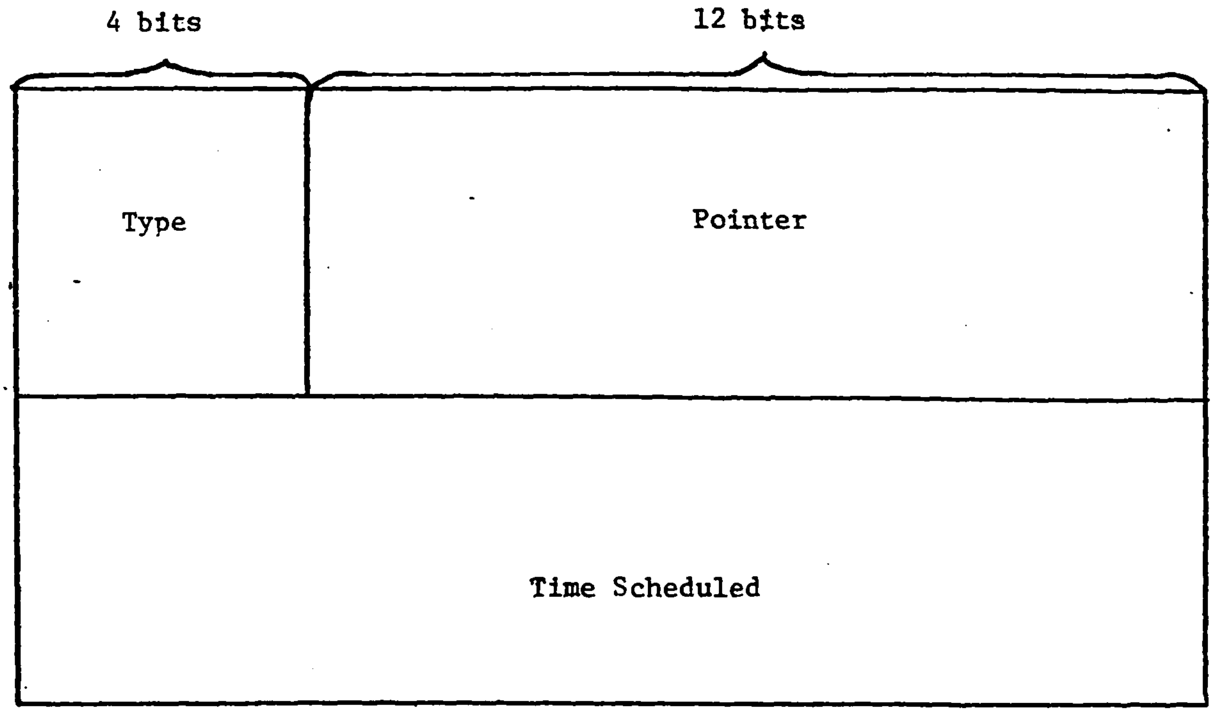
8.2 Scheduler

The routine that referees all computer functions is the Scheduler. Every sixtieth of a second it receives an interrupt, determines which routines are active, and then executes them in the order that they were scheduled. As a result of that execution, the scheduler either unschedules the routine or reschedules it to recur at a later time. Each entry includes the time at which it is to be invoked, the starting point of the routine, and the type of routine it represents (figure 8-1). Currently, there are only three types of schedule entries but more will be needed:

1. The one-shot is executed once and then unscheduled not to be executed again. An example of this would be the routine which flashed the strobe light in the Psychic Space exhibit.

2. The cyclic routine is scheduled to be executed every so many interrupts. Once executed, it is automatically rescheduled to occur again after a fixed number of interrupts have passed. The cyclic routine which read the floor was scheduled to be called every tenth of a second. It was not necessary to read the floor every sixtieth of a second because people don't move that fast.

3. The sequential entry causes a series of routines to be executed, although not all at once. In fact, the entry contains a pointer to a list of routines and the relative time increments at which they are to occur, (figure 8-2). When the scheduled time arrives, the first routine is executed, the pointer in the entry incremented so it points to the address of the second routine, and the time increment with that address added to the current clock value to become the next time the sequential entry is scheduled to be called. In Psychic Space the series of notes preceding the light activating the phosphors, the actual switching on and off of the light, and the twenty second pause afterward were all the result of a single sequential entry in the schedule.



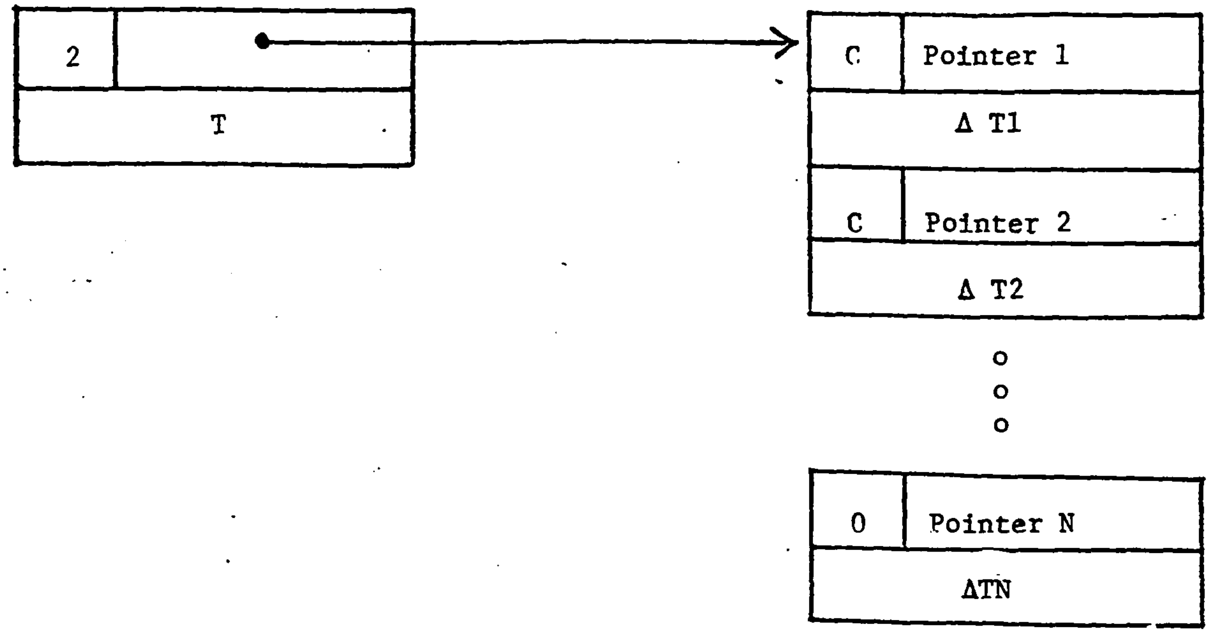
Type: type of schedule entry

Pointer: contains address of scheduled routine

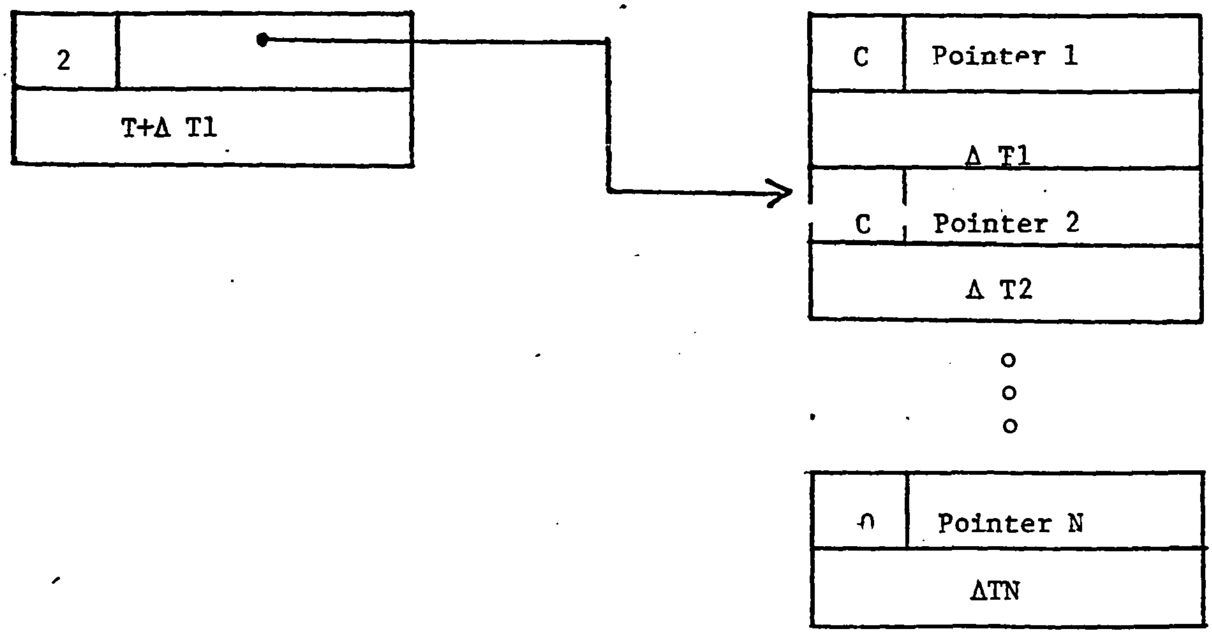
Time scheduled: clocktime at which this entry
must be serviced

Schedule Entry Format

fig. 8-1



Sequential clock entry for Time = T-1



A+Time = T+1 The first routine has been executed and second is scheduled.

Sequential Clock Entry

fig. 8-2

8.3 Response Cycle

The basic unit of processing controlled by the schedule might be called the Response Cycle, for it includes the steps required to detect any behavior and then to select and effect the response. Its attention is directed to the problems of deciding what has happened and then determining what will happen next.

8.3.1 Input of Sensory Data

Since none of the sensing hardware currently used causes an interrupt each time the person moves, their state must be sampled periodically, the rate varying with the device. While the floor was sampled only ten times a second, a video sensor capable of detecting smaller movements might be sampled more often.

8.3.1.1 Raw Input

The first problem is simply to read in the sensory data. With the floor this requires outputting five bits to select a row, reading it in, and continuing until the whole floor has been read. With the video outline detector described in chapter 6 the process would be more involved because the reading would have to be synchronize with the scan of the television camera. It would be necessary to enabl an interrupt routine to be triggered by the horizontal synch pulse. This routine would read and store the scan line number and the left and right boundaries in the outline array. The routine would continue to be called until an entire frame had been sampled at which point the interrupt would have to be disabled.

8.3.1.2 Simple Event Detection

Once the input is stored it must be compared to previous readings to determine what changes have taken place in the environment. These discrepancies are events and must receive responses. In the case of the floor both newly closed or opened switches are identified and used to compute the person's location. With the video sensor the changes in the person's outline would indicate what parts of his body were moving and how much.

8.3.1.3 Discrimination Among Individuals

There additional steps that must be taken if several people are standing on the floor. In order for the program to respond uniquely to each person's movement, it must be able to correctly associate each simple event with the person who caused it. Each event is usually assigned to the individual who was closest to it when it occured. Once assigned the event will be used to determine the participant new location. If two people enter the space walking close together, the computer will not realize there is more than one person until it receives two events which occur far enough apart to be resolved as different people.

8.3.1.4 Detection of High Level Events

The information gathered so far is common to all interactions using the hardware described. These events are then subjected to additional tests which are specific to the particular interaction. In the Maze each movement had to be checked to see if a boundary had been crossed or the participant had entered a new part of the Maze or if he had spent too long in one part of the Maze without advancing. In another interaction the program might use the participant's rate or direction of movement to determine the environment's response.

8.3.2 Output of Response

8.3.2.1 Direct Response

Once a unit of behavior has been detected and its agent identified, another kind of routine must select the appropriate response and schedule it (output is always directed by the schedule; this allows subsequent responses to cut short an earlier response in favor of a new one). The simplest response is a single event like the sound footsteps in Psychic Space, although even this involved the selection of a pitch based on the participant's position. The stretching boundary in the Maze was just somewhat more complicated. Some relationships may require time to establish and cause a response which goes on for seconds after the precipitating action. In one interaction the computer remembers a given sequence of actions and echoes it with variations later in the experience. To make this repetition meaningful the computer must call attention to these steps as they are made by responding to them in an exaggerated manner so when this sequence of responses is repeated later, it will be recognized as the product of prior activity. To be identifiable, both the pitches accompanying the original footsteps and the pauses separating them must be preserved. Thus, the display programs can be intimately involved with the sensing routines over a period of time before the simple idea of responding to past events has been conveyed.

The response routines may also have effects which are not recognizable as responses. For instance, a visible change in the maze must be accompanied by a change in the routines which monitor the participant's movements to make sure they are legal. A response may also change the schedule that governs the overall experience.

8.3.2.2 Unresponsive Display Context

The computer also has to maintain a displayed environment like the Maze independent of what the participant does. Or the display programs might be responsible for the behavior of a simulated entity which inhabits the same display space as the participant. Such an entity would have its own rules of behavior, perceptual limitations, and peculiar physical articulation as it moved.

8.3.2.3 Output Device Drivers

Whatever the use of the output there are low level routines to drive the hardware which generates the display. These routines must be compatible with the Scheduler, particularly if they are to generate a series of outputs from a single algorithm. An example is suggested by the array of lights in the floor described in the previous chapter. Each footstep could result in an explosive pattern of lights that would radiate from the participant's foot after each step. The routine to do this would compute each change in the pattern based on its current state. It would have to recognize when the pattern had reached the edge of the floor and unschedule itself.

8.3.3 Operating Utilities

While the show is operating, the computer will need some sort of operating system to control not only the direct sensing and response functions but also the communication with external storage devicies and other CPU's. In the past no single machine had all the facilities required to implement the author's conceptions. While the Adage had graphic capabilities, it could not be moved from the Computer Center or easily interfaced with nonstandard devices. Thus, while the Maze display was generated by the Adage, the direct control of the environment was the responsibility of the PDP-11 which also accomplished the data communication between the two machines.

8.3.4 Dreaming

Last, and perhaps of least obvious importance, are the routines executed only when the environment is empty. Through these programs the computer would ruminate over its recent experience, pondering which of its responses had been most successful in eliciting the interest it desired. This process is analoguous to dreaming and could, after an evening's reflection, arm the computer with a new set of hypotheses with which to greet its audience the next day. For useful learning to occur these programs would have to be run on larger machines than those used to control the interaction.

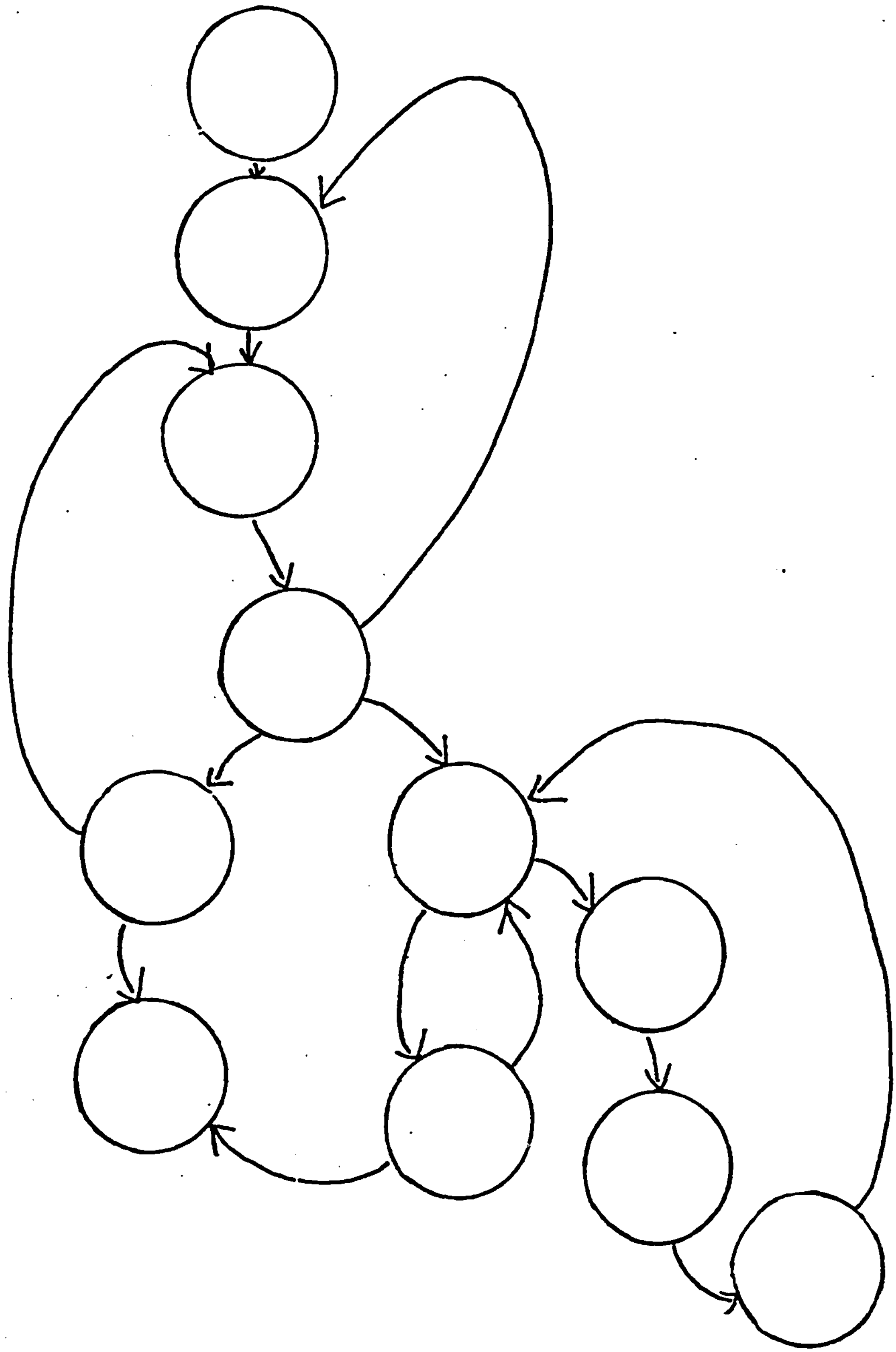
8.4 Composition

8.4.1 Composition Schedule

The artist's plan for the interaction is effected through the Composition Schedule. Currently this is a single sequential entry in the main schedule pointing to a list of times or conditions at which the feedback relationships will change. It allows a specified amount of time for introducing each new idea and reflects aesthetic choices about the timing, order of effects, and the conditions for the transitions from one relationship to the next. These choices often require considerable tuning before the experience unfolds in a coherent way without causing bewilderment when the relationship is not understood or boredom when it continues after its novelty has been exhausted.

8.4.2 Composition as a Net Structure

The sequential schedule used so far is but a special case of broader concept, a net structure which the participant traverses through his activity (figure 8-3). The nodes of the network would be decision points which alter the subsequent course of the experience. The links between nodes are similar to the sequential schedule described above. The path each participant actually takes will be a function of what he does. There must also be a governing structure which assures that the participant is arbitrarily placed on a path that ends the experience after he has been in the environment for his alloted time. The sequence of events also reflects the recent experience of the environment, with unused paths becoming more likely



Net Structure Controlling Interaction

fig. 8-3

so all possibilities are used in the long run. This feature would personalize the experience, giving consecutive people different experiences. In comparing notes afterwards they might discover that while their experiences started similarly they diverged beyond a certain point. Thus their exploration of the environment would continue after they had left it.

8.4.3 Experimental Tools

For each of the input or output devices, routines which test and explore their operation are needed.

8.4.3.1 Testing an Input Routine

For the input devices it is necessary to provide sample data to see how well the interpreting programs perform. One example would be the program used to test the code for discriminating among people on the floor. The procedure was to record the paths of different people walking around the floor at different times. Then the paths were merged so they would look as if they were occuring simultaneously and fed into the sensing program. Since the computer had access to the separate paths, it could test the effectiveness of the program's attempts to resolve them. On the color T.V. in the studio different color was used to represent the switches that each individual was standing on at a given moment. The computer-generated video image also included an indication of how the sensing program resolved each pattern of switches into distinct individuals. This tool was very useful in evaluating different schemes for handling the pattern recognition problems associated with the floor. Similar problems will be required for each sensing system.

8.4.3.2 Exploring Output Possibilities

The possibilities of each display device must be explored and understood before the composer can make the fullest use of the hardware at his disposal. Each device will have its own idiom, its own repertoire of particularly effective light or sound events. The programmer must have a display generator and editor which gives him complete freedom to define and name sets of outputs, to group the sets into larger patterns, and to produce sequences either element by element or algorithmically.

8.4.3.3 Experimenting with the Interaction

The composer/programmer should be able to modify the relationships between the inputs and outputs with complete facility even as he moves around the space testing effects and asking an operator to make the quick changes that will allow him to experience alternatives. To do this his programs will have to deal with interlocking routines involving several levels of interrupts as glibly as ALGOL defines mathematical algorithms. The results of this experimentation will be small units of interactions, specific relationships and the transitions between them. The assembly of these bits and pieces into a score for an interactive experience is accomplished through the Composition Schedule described earlier. The performance of the score is left up to the participant.

CHAPTER 9

STANDING FACILITY

9.1 Introduction

Now that the medium has been defined and its possible elements identified, it remains to design a long range strategy for continuing this work. The author's experience suggests that gallery shows may actually impede the development of the environments. While it is true that tremendous energy is generated by the immediacy of a show, much of this is dissipated in overhead that produces no long term result, i.e. the ability to produce further work. Instead a decision has been made to focus future effort on the creation of a standing facility, not only general enough to implement all of the interactions described so far but also capable of fostering the application of responsive environments to other areas. The key to this versatility will be a system of standardized electronic interfaces to ease the interconnection of a wide range of sensors and display devices. Several increasingly more powerful configurations will be described each of which would support a wide range of possible interactions to be explored by simply changing the programs.

By eliminating the need to physically construct the environmental space and to secure short term commitments for the equipment borrowed for each show, a standing facility permits the author to concentrate on the composition of experiences rather than the construction of hardware. Without pressure from a line of people waiting to get in, longer interactions like the Maze can be developed.

The public can be invited to the facility so the interactions can be tested and tuned with a live audience. Remote or travelling exhibitions would occur only after the compositions had matured and the hardware made easily transportable.

9.2 Controlling Core

The controlling core which consists of the central computers and the surrounding electronics is the source of the facility's generality. It is centered in a single processor which mediates all of the immediate functions of the environment, although in an advanced system the direct acquisition of sensory information and the driving of output displays can be delegated to satellite computers. A fourth machine of larger capacity could handle more sophisticated analysis of the input or the preparation of those complex outputs which need not be effected in real-time. Learning and planning would also be performed by this machine.

Just as the computers' operation can be varied by changing their programs, the electronic interfacing can be structured in a way that divides the less general input and output functions into separate modules which can be easily concatenated to build the composite function needed for a particular application. Once the general I/O structure has been defined, it can be easily extended to accomodate additional sensory inputs or output displays by replicating these basic modules. A number of module functions, accompanied by examples of the I/O tranducers that might require them, will be described below.

9.3 Interfacing

The electronics radiating from the core must allow the computers to control as many and as complex processes as possible. Typically these machines will input or output 8, 12, 16, 24, or 36 bits in parallel depending on their word size.

9.3.1 Multiplexing

While there may be several such I/O words, it is often necessary to expand the effective number of words by multiplexing. The input of one word and the output of another can be used as data buses while another output acts as an address bus directing traffic along the data buses. The output buffer selected by the address bus accepts information from the output data bus and then holds that value while that bus is used to update other buffers. Similarly the input data will be arranged as parallel words along the input data bus and gated in when selected. Extending the I/O buses is simply a matter of connecting another buffer or gating module to the bus.

9.3.2 Words as Discrete Bits

Some of the I/O modules will be used to control or communicate the binary states of a number of unrelated devices. Thus individual input or interrupt bits may be tied to pressure switches, electric eyes, or threshold detectors sensitive to light or sound amplitudes, sound frequency, or movement as indicated by an ultrasonic motion sensor. Similarly an output bit may be used to trigger a strobe, to turn on a light or speaker, or to select the path for an analogue signal to follow through an audio or video synthesizer.

9.3.3 Words as Parallel Bits

A word or group of words can be used to read or set an array of switches. For instance the sensing floor used in Psychic Space was read in as a sequence of twenty-four sixteen bit words. Similarly the array of lights planned for the graphic floor of section 7.3.2.1.2 could also be implemented as a very long sequence of pattern words. Communication with other computers could also be accomplished a word at a time.

9.3.4 Analogue and Digital Conversion

Since the computer represents information in a digital format while audio and video signals are analogue, it is often necessary to use converters to translate information from one form to the other. The computer may want to know the magnitude of a variety of analogue signals such as the volume of a person's voice, the strength of a signal bouncing off him, or his weight as reported by a strain gauge. A rapid sequence of such readings made by an analogue to digital converter (ADC) would allow the computer to respond to the waveform of his voice or heart beat.

Likewise the computer can produce a waveform as a series of voltages output through a digital to analogue converter (DAC) or use the DAC to control the waveforms generated by the voltage controlled oscillators and voltage controlled amplifiers on a sound synthesizer. A voltage level can also be used to set the threshold for video keying or to control the intensity of theater lighting. A pair of DAC's can control the deflection voltages on a graphic display while additional signals can place, scale, and rotate an image on the display screen. Three such voltages could define the color and intensity of a color video beam. All analogue inputs and outputs should be designed for a standard set of voltage ranges and impedances so all devices are compatible.

9.3.5 Counted Input and Output

The digitizing or generation of time intervals can be accomplished by external counters which are set or read by the computer. By zeroing and starting an external counter at one zero crossing and saving its value at the next, a rough indication of a signal's frequency is obtained; the higher the count the lower the frequency. A count that started when a signal was emitted and stopped when its reflection off the participant was received would provide a means of estimating his distance. The video outline sensor reports two counts both started by the horizontal synch pulse and one halted by the first black to white transition and the other by the last white to black transition.

Output counts can be used for pulse width modulation or power control. The output of the counter would be matched against a previously set final count value after the clear and start pulse. When the count reached the final value, the pulse would fall. A series of counts and digital values would be used to control the envelope of each harmonic in the synthesizer described in section 7.3.3.2. After each counted interval the circuitry would automatically insert the next value for the DAC controlling the amplitude of the harmonic.

9.3.6 Parallel/Serial/Parallel Conversion

External parallel to serial and serial to parallel converters could be used in the sending or receiving of serial bit trains in data transmission or the generation or analysis of video images.

9.3.7 Voltage Translation

It may also be necessary to control high voltage or AC devices such as motors or lights. Either triacs, relays or power transistors can be packaged in modules to be used for these purposes. With very low amplitude signals such as those generated by body functions special amplifiers will be required to bring them up to a range compatible with the rest of the circuitry.

9.3.8 Protection Circuitry

It is often desirable to use protection circuitry to prevent interfacing errors from damaging the computer. This precaution is mandated when there are frequent changes in the interfacing or where unskilled students are allowed to modify the hardware. Opto-isolators, relays, and isolation transformers are a few of the many ways this function can be accomplished with the first becoming more and more important. These components should also be assembled into word size modules that can easily be inserted into any signal path.

9.3.9 Data Transmission

Data transmission may be required on either input or output and can be effected in a number of ways depending on the distances involved. For the shortest distances a line driver and line receiver pair can be used to send signals within the lab. Radio transmitters and receivers may be needed where signals are being sent to or from a moving person. For longer distances data may be impressed on an audio or video signal and sent over existing cables. The general facility should make full use of all available data channels, e.g. telephone, video cable, for these reasons. First the data and signal processing capabilities of the studio will be available anywhere the communication network touches. And second devices that cannot be made part of the lab but which are available to the communication system can be used by the lab exactly as if they were physically present.

In Metaplay and Psychic Space the graphics power of the Adage was available in the gallery although the machine was a mile away. Similarly there is a disk in the Space Science Center capable of storing 500 video frames. It too could be tied into a distributed interactive facility. The final reason is that communication is one of the themes of the author's work. The video space concepts in particular involve interaction through a communication medium.

9.3.10 Audio Interfaces

There should also be a standard audio interface that is maintained throughout the synthesizer and is compatible with all other analogue circuitry and accessable to the ADC's. Thus, all input and output impedances should be consistent. Audio amplifiers and switching circuitry should be arranged in easily accessed modules.

9.3.11 Video Interfaces

Similarly video signals should be standardized and obey the additional discipline imposed by maintaining synch throughout the video system. To do this a special high current synch generator is required as well as a synch stripper which can be used to slave the master synch generator to an external signal such as that generated by a video tape recorder.

9.3.12 Transducers

The last step in interfacing connects the actual transducers which sense the participant or produce the stimuli which he perceives as the environment's response.

9.4 Development Stages

With the underlying system of interfacing just outlined, the development of the input/output capability can proceed through several natural stages which will be described with an indication of which interactions are possible at each level.

In the first stage the scope of the interaction will be confined to the lab and the emphasis on developing the computer's awareness of the participant and displaying that with simple auditory responses.

In the second stage computer graphics and live video images will be combined to provide more complex responses.

The next step would be to tie the studio into a video cable network making its power available in many places and interactions between widely separated participants possible.

Then the final marriage of computer graphics and video image processing will be effected yielding a new electron beam medium.

As the input and output media mature, the programming will become more important until Aritificial Intelligence techniques implemented with special hardware provide the computer with a complete analysis of the participants' behavior and the means of answering with increasingly intelligent responses.

9.4.1 Input Stage

In the first stage, which the author has partially implemented in his studio, the emphasis is on the computer's perception of the participant. The inputs should include the combination of the sensing floor, the video outline sensor and perhaps the occluded light sensor. The outputs would favor the sound because greater complexity can be produced for a small investment and from a single source. An environmental element could be added by distributing speakers throughout and allowing the origin of the sounds to move.

The visual outputs would be limited to discrete sources such as the strobes of the Pulsa Group, the tubes of Glowflow, or the lines of light for the Space Dance (Section 7.3.2.1.1).

The ultimate expression at this level of processing would be a large array of lights like that suggested for the graphic floor (Section 7.3.2.1.2) which could provide a large number of possible interactions. With this level of facility only the barest representation of the environmental medium is achieved. While the inputs might be relatively complete, the outputs are limited to abstract events with little ability to convey symbol, gesture, or meaning, and no way of representing a context like the Maze in which the experience can occur.

Nevertheless a wide variety of interactions can be composed within such a facility. The responses would start with a direct display of the computer's ability to perceive and then lead to variation, repetition, and omission around expected patterns. Shaped spaces and tunnels could be constructed to test the effect of the physical environment on the interaction. Finally, people from other fields such as dance and psychology could perform preliminary experiments in such a laboratory.

9.4.2 Computer Video Stage

In the second stage the emphasis will be on the development of more elaborate visual responses based on the simple merger of computer graphics and video images. The hardware required will include a graphic display computer with a data tablet and video output, a number of standard and infrared video cameras, and two television projectors.

Used by itself the graphic display can provide contexts like the Maze in which the experience can occur. By adding the participants' video image the live drawing aspect of Metaplay can be expanded and the automatic generation of computer images responding to the participant effected with the help of the video outline sensor. With a number of cameras collage effects could be created by computer control of the video switching and the results preserved on video tape or film as well as being projected in real-time. If there are two separate environments, in the lab, the video touch concepts (Section 6.3.6.3) can be explored.

The versatility of the graphic display and the importance of his image to the participant will motivate a tremendous number of possible interactions in such a facility.

9.4.3 Distributed Facility

This step is the distribution of the computer video facility to include remote places and devices. A system of standard video interfaces will be developed which permits the transmission of data, audio, and video signals over a two-way television cable network. In this way remote devices could contribute to the environment's processing power which would then be available wherever the cable touched and not just in the studio. Responsive techniques would be used for theater lighting, dance concerts, and the control of sound or image processors elsewhere. Most important, long distance interactions like the Video Amplifier can be implemented.

9.4.4 Plastic Video

The next step is to make a complete commitment to the development of the plastic video medium described in section 7.3.2.2.4. The full merger of computer graphics with computer controlled video processing will open the door for a wide spectrum of spectacular interactions when these images are displayed on all walls of the environment with color television projectors. Such a display would probably be generated as a single high resolution image and then fed into a series of scan converters each of which would generate a different subimage for projection. By surrounding the participant with imagery the environment will completely immerse him in visual sensation. In addition, the ability to move, shrink, distort, or dismember the participant's image as he watches will undoubtably have tremendous impact.

Clearly such a facility would allow the environmental artist to pursue his vision. The behavioral scientist or educator would and speakers at every table. Thus, the performing artist could control light and sound displays that moved among the audience. Or the audience could control these displays with their keyboards, perhaps competing or cooperating with each other to achieve the desired effects. Audio or video records of their idle chatter or exaggerated gestures could be used later in the evening as part of improvised skits where their behavior is edited and comic additions and comments inserted by the staff. With such a facility an inventive group of artists could create a new dimension in entertainment as well as Art, for both areas should benefit from the new technology.

9.4.6 Artificial Intelligence Projection

In the very long run it can be assumed that the computer will be able to monitor human behavior in complete detail in real-time, i.e. the pattern recognition problems will be solved.

Computer processing would be so powerful that the participant would perceive a completely convincing world where he was able to act with complete physical freedom. In this world he would encounter other humans, some completely simulated and others the projections of real people like himself, and a set of circumstances within which he can participate, affect events, or control them depending on how much he asserts himself in the pseudo situation.

The computer will be able to respond with either its own intelligence or to use programs that reflect the artist's. It will constantly refine its ability to interest and entertain by learning about people in general and learning to recognize individuals it has also find that a wealth of new approaches could be tried for their work, particularly since any of their specialized hardware such as body function sensors could be easily interfaced with the system. Performing artists such as dancers and musicians would also find a whole new realm of experimentation opened for them. More such extensions will be discussed in Section III.

9.4.5 Electron Arts Cabaret

As an adjunct to a general facility the author envisions the development of a more casual environmental entertainment feeding off his work. To keep the emphasis on experimentation rather on the creation of slickly finished pieces, the audience must be involved in the experimental process, witnessing rehearsals rather than productions. The vehicle for encouraging such an interaction would be a circular coffee shop or cabaret surrounded by performing and display spaces radiating out from it. The goal would not be to maintain interest in a constant passive entertainment but rather to periodically dim the lights, interrupting conversation with brief experimental presentations lasting no more than 15 minutes, the maximum for experimental forms. This format would relieve the artists of the burden of entertaining; the audience would amuse themselves much of the time but still be available when there was something to show.

The area where the audience was seated would be fully wired, making them part of the environment. There would be arrays of lights in the floor, tables and ceiling as well as keyboards, microphones, seen before. It will possess a personality and a sense of humor as befits an aware entity.

Since the artificial experience would be indistinguishable from the real, it would compete with it for each person's attention just as the television does today. In fact, since the artificial experience would be composed it could also be much richer and more concentrated than real life. Furthermore, because the environment would not be bound by the usual laws of physics, the experience could involve physically impossible events like putting a male participant in a female body and having the rest of the characters act appropriately. Such experiences could lead to a fuller empathy among people. One unsettling thought does occur: if our existence were but part of such a simulation we would have no way of testing it, although the fact could be revealed by the Programmer.

CHAPTER 10

SCIENTIFIC APPLICATIONS

10.1 Introduction

While cybernetic thinking pervades the sciences there are several fields where the techniques described earlier may find their most fruitful application. The first section on Computer Science reflects the origins of the author's interest in a rich interaction with the computer. The rest of the chapter examines the use of the environment for manipulating human behavior in both therapeutic and instructive ways in the areas of Psychology, Psychiatry, and Education. In each of these domains it is the ability of the computer to control stimuli and define dynamic, complex behavioral relationships that makes its application attractive.

10.2 Computer Science Applications

10.2.1 Introduction

There are several aspects of Computer Science which may be influenced by the ideas and techniques developed for the responsive environments: the man-machine interface, the act of programming, real-time simulation and robotics. Compared with each of these domains as defined today, the problem the environment poses is more general and so may produce insights of interest.

One of the tasks the responsive environment facilitates is a more complete exploration of the man-machine interface. Currently the computer allows us to communicate with just the keyboard, light pen, data tablet and track ball; whereas the environment allows us to communicate via our voices and the physical movement of our bodies. Traditional output devices are more varied but common experience offers only the line printer, plotter and graphic display as opposed to electronic sound, projected graphics, speech, lighted floors or laser beams that the environment can use to express itself.

The responsive medium poses two questions: what are the ways that a man and machine might interact and which of these are aesthetically most desirable? Some of these new modes of interaction, or the tools used to implement them, may well prove to be of practical importance, e.g. the video keyboard which a person plays by moving his image around the screen. Such a device would have no mechanical parts to wear out and would allow the operator physical exercise as he controlled it.

10.2.2 Programming

The environments are not suggested as a means of programming, but they are a way of experiencing a running program, a much richer and more involving way than the one the programmer is usually subjected to. Every programmer shares a common need when he is debugging one of his programs; he must be able to see what it is doing. The programmer works under the worst possible feedback conditions; he must anticipate every contingency ahead of time and yet has difficulty determining what actually happened afterwards.

One might mitigate these problems by enriching the programming environment, providing light and sound displays through which he could monitor his programs as they were running. Earlier machines were often equipped with a speaker tied to the contents of the accumulator. The programmer came to know the proper sounds for his program to make, and, if an unfamiliar one occurred, it often signalled the presence of a bug. This experience is still available for the programmer of a large system who is allowed to be present as his job is run. By watching the tapes, disks, console lights and other peripheral equipment he can see what his program is doing and at what point it goes wrong.

In addition to passive monitoring the programmer needs much more versatile ways of controlling the execution of a program while it is running. He needs to be able to speed it up, slow it down, back up, and skip with ease. The author was implementing a system with these capabilities on the PDP-12 before he realized that the general approach to the problem of interacting with the computer led to an art form instead of a single tool. We have found that even such a simple expedient as video projecting the contents of an alphanumeric display frees the programmer to walk around the room as he ponders his problem.

10.2.3 Real-time and Simulation Programming

The responsive environment resembles two kinds of well defined practical problems: real-time and simulation programming. Not only do the environments involve all the problems of both areas in their full generality; but they add the further dimension of interactive composition. Whereas a flight simulator only has to represent the kinds of interactions which a pilot might have with his controls, the approach of the environmental software is to be completely device and interaction independent and be capable of presenting any relationship which might be found in any environment, real or imaginary. Such a general approach will undoubtably benefit these practical areas by attacking problems which they have so far not needed to solve, particularly our intention to be able to intercept any level of operation and compose within it.

One system developed for compositional purposes has already been found to have practical application. Groove, developed by Bell Labs as a system for editing the time function associated with generation of electronic sounds, has been found to be relevant to the control of machine tools! The domain of problems associated with the environments is far larger than Groove's because they require systems for editing and composing sensing capabilities, output relationships, as well as event scheduling.

Most visual pattern recognition only considers static images. The responsive environment will be one of the first applications to face the problem of recognizing dynamic patterns. As he moves around the room, the computer must parse the participant's movements into the smaller gestures which have meaning to him. If the computer succeeds it will respond at appropriate times. If it fails, its responses may constantly conflict with the flow of the participant's behavior, just as a typewriter with an oversensitive keyboard is disconcerting to use.

10.2.4 Robotics

The last set of requirements is also related to Robotics. In fact, it is reasonable to view the responsive environment as an inwardly aware, immobile robot. The participant enters the perceptual space of this robot which senses his presence and responds to him. While we typically think of robots as mechanical monsters stumbling around on wheels or metal legs, there will probably be more distributed HAL-type robots than mobile ones for the foreseeable future, because electronics is progressing even more rapidly than mechanics or portable power storage. In every situation where we now deal with a man who acts like a machine, i.e. whose job function is so narrowly defined and repetitive that there is little room for him to express his humanness, these functions could be done as well and perhaps more naturally and more humanly by a machine. These machines will be required to speak and listen and perceive the people in their immediate vicinity—which thus becomes a responsive environment.

These environments would seem more interesting as robots if they could move and manipulate within their spaces, and in a way, they can.

One important aspect of movement is the movement of attention, the ability to "go see". The environment can do this by selecting among a large number of sensors that give it alternative perceptions of the participant from different vantage points.

Similarly, the computer can be said to manipulate its environment if it can purposefully control the behavior of the people within it. The example of moving the participant to the starting point of the Maze cited several times earlier demonstrates that the computer can effect changes in its environment. While other work in the field concentrates on the physical behavior of the robot it might be argued that the responsive environment is a tool for developing its personality, its ability to interact with humans. The techniques for making the computer interesting and playful developed in responsive environments will be easily transferred to mobile robots although a self-contained creature constrained to a physical body is a relatively limited tool for interacting compared to an environment which completely surrounds its audience.

10.3 Applications in Psychology

10.3.1 Introduction

The application of the responsive environment to psychology is especially natural if you recognize its minimal goal is to maintain the participant's interest. The environment can be used as an experimental tool which gives new freedom in controlling stimuli and recording responses. This power permits a more thorough analysis of accepted dimensions such as reinforcement and learning. After considering general applications, we will suggest the exploration of a new area, the study of change and its effects on human behavior. Finally, we will consider ways that the human output bandwidth might be increased by methods such as modulating body functions or body posture.

10.3.2 The Responsive Environment as an Experimental Tool

10.3.2.1 Automating the Experiment

The responsive environment is essentially a flexible tool for presenting stimuli and analyzing behavior, a generalized Skinner Box which can automate many of the experiments psychologists have done in the past. It will lead to much greater experimental complexity, to experiments which take advantage of the new capabilities of the computer and push them to their limit. Rather than thinking of a single reinforcer, the psychologist can examine patterns or sequences or rhythms of reinforcers. He can program the computer to respond immediately to contingencies which are beyond human reflexes, automatically taking into account probabilistic schedules and past history. Longer experiments will not be limited by the experimenter's endurance. He will be able to interact with his experiment as it is going on, using sequential testing techniques so no data is taken beyond that necessary to prove or disprove a certain hypothesis.

10.3.2.2 Permitting Gross Physical Behavior

One of the advantages of an environmental tool is that it gives the experimenter the ability to deal with gross physical behavior instead of the more limited button-pressing, pencil pushing, or peeking usually involved. Quite likely the introduction of physical movement would interfere with some of the behavior we thought we understood based on studies of sedentary subjects performing isolated tasks. One area which is particularly promising as an aspect of gross physical behavior is perception which will be discussed shortly.

10.3.2.3 Not Recognizable as an "Experiment"

The aesthetic environment is useful because it is not immediately recognized as an "experiment". Since most subjects involved in psychological experiments today are quite sophisticated about the interests of psychologists, there is no real possibility of studying spontaneous behavior. Instead scientists study the self-conscious behavior of people who know that they are in an experiment. An experiment presented as entertainment would be more likely to evoke natural behavior and because of its uniqueness would have little difficulty attracting subjects. Assuming that the environment was programmed to run several alternative experiments it could after a few screening questions or even interactive tests select and run the interaction that was most appropriate to each subject.

10.3.3 Perception During Physical Behavior

The environment allows the psychologist to focus on perception as part of behavior and not a disconnected behavior by itself. Perception is inextricably related to physical behavior. We perceive and, based on the perception, we decide to act. Often in order to improve perception;

e.g., seeing something a distance away, we approach to see it better. Problems like pattern recognition are further related to physical behavior because acting cuts down on the information handling capacity of the brain. The moving perceptual process is not like sitting and analyzing a photograph, it is much rougher scanning and feature detection. We are somehow filtering out most of the information and only accepting those parts of our perception which are immediately relevant.

10.3.3.1 Perception of Athletes

By bringing the study of perception into the realm of active behavior, we can study the specialized physical perception of athletes who must use only the most highly refined pattern recognition techniques. The kinds of information they use and the interpretations they make are hard to determine at this point because we don't know exactly what it is that they attend to. We have the same problem Leonardo da Vinci had when he tried to study the flight of birds. He misunderstood flight because he could not slow down the process and examine its smaller elements. In the same way we have never studied perception in motion because we have never had the means of controlling stimuli and recording responses with the speed and resolution the computer permits. By outfitting an athlete with kinesthetic sensors that transmit all of the information about his body position and then giving him a perceptual task within an environment related to his own area of excellence, we have the means of studying his perception. Since the computer completely controls his inputs and monitors his outputs, it should be possible to isolate his perceptual process. This information can be used to construct a model of the human perception and information handling capacity pushed to its limit in one domain. By studying a number of such perceptual specialists new insights and generalizations might result.

10.3.4 Studying Feedback and Learning

10.3.4.1 General Feedback Generator

The environment can also focus on the general issue of feedback. Experiments involving the spatial or temporal displacement of feedback can be accomplished with ease as in the Maze where the feedback representing the person's movement was suddenly rotated ninety degrees. In fact the environment is an incredibly versatile feedback system allowing the experimenter almost complete freedom to assign arbitrary feedback to almost any action.

While the necessity of at least the minimal feedback required to do a task is recognized, the possible relation of feedback to sensory deprivation is not yet explored. It is recognized that the human nervous system need a certain amount of stimulation for comfort. It is further recognized that certain activities in of themselves do not provide sufficient stimulation and so lead to a sense of frustration, boredom, or anger even where there is no degradation of performance. It is for this reason we find Muzak piped into department stores and assembly lines and women turning on the television while they do the housework. What has not been done to the author's knowledge is to enhance the feedback derived from a given task so that the supplementary stimulation is a consequence of the task itself, increasing a worker's concentration on the task rather than distracting him. Concrete examples of how such ideas might be used in a practical context will be developed in Chapter 12.

10.3.4.2 Varying Reinforcers

The concept of reinforcement is crucial to much of current learning theory and, like feedback, there are many ways the environment can be used to experiment with it. The distinction between feedback and reinforcement is that feedback is the information generated by the activity whereas a reinforcer is a favorable result distinct from the activity which makes the activity more likely to recur. Most learning experiments assume the existence of a single reinforcer that is sufficient to elicit all the behavior involved in the experiment. By working with starved rats, of course, it is relatively safe to assume that food will be reinforcing. On the other hand, in many learning situations, e.g. school, the animals involved are completely sated. What reinforcer might be effective in this situation is impossible to predict with any certainty. Furthermore, the assumption that any given reinforcer would maintain its effectiveness for a long period of time, would seem to violate basic economics; the value of any given reinforcer would be expected to wane as one's experience with it or supply of it increased.

10.3.4.3 Interest in Learning

Thus a problem of interest to all learning and education is identified. How do you keep someone learning? How do you motivate him when you cannot deny any of his basic needs. The environment like Computer Aided Instruction systems, programmed texts, or indeed, any method of teaching, has as an absolute minimal requirement the need to gain and maintain the participant's interest. In fact, the environment provides for studying the problem of maintaining interest either as accompanied by or isolated from the teaching of content. The educational system has ignored this problem as if it did not exist. Students are assumed to be interested even though many of them clearly are not. The grades given in courses or the simple indication given by a programmed text that an answer is correct may not be sufficient to maintain the learning behavior. For instance, while a Plato terminal was temporarily installed in the UW Computing Center, the author and a group of other graduate students worked through what seemed to be a difficult problem in Chemistry, given our immaculate ignorance of the subject. We felt cheated at the end when merely told our answer was correct; we expected nothing less than fireworks at that point. Fireworks, thunder and lightning, and other such flamboyant responses are just part of the environment's wildly variable repertoire.

By constantly varying the reinforcer the environment should be able to get the participant to persist in activities which would otherwise fail to captivate him. The simplest environment would be based on a single button which would be used to control lights and sound through the computer. The question would be how long the participant could be induced to continue pushing the button. Many strategies might be used. A series of iolated sound responses might be followed by small patterns of lights, then by rhythmic alternation between these modes with their scope becoming larger and larger until the whole space was affected by the button. Or, the button could become the only key on a strange typewriter where the letter chosen was a function of the time that had elapsed since the last time the button was struck. The participant would continue to play with the button as long as it provided relationships which took time to comprehend and once mastered changed in ways which constantly surprised him.

10.3.4.4 Teaching Interactive Relationships

This trivial environment controlled by a single button bears a striking similarity to a piece of music. Just as each note might be thought of as a reinforcer which induces further listening, each response by the environment should encourage further action. For this process to maintain a participant's interest over a period of time it must involve a subtle form of teaching. If the result of every action is either known beforehand or completely unknowable, there is little chance a participant will remain involved for any length of time. On the other hand, if the reinforcers are regular enough to create expectations about the next occurrence, both the verification and the violation of these expectations can be reinforcing.

These expectations must be taught. Each relationship must be introduced, repeated until it becomes expected, varied around the expectation and finally violated in a way that leads into the next relationship. Once a relationship has been learned, it can be invoked later when an unknown rather than a familiar relationship is expected. Such flirtation with a person's expectations involves a subtle form of teaching which should be studied because it provides a general structure for maintaining interest through varying reinforcers. If this structure were presented in parallel with an independent development of subject matter, the interest it developed would help motivate learning the material. If the student knows that the response that reinforces each correct answer will be part of a continually interesting pattern, he will be motivated to persist out of curiosity about the next reinforcer.

It is the maintenance of curiosity that is reinforcing here rather than any intrinsic value of the reinforcer itself. Consider the well known fact that variable reinforcement schedules lead to more persistent learning than other schemes. What is now being suggested is that fixed schedules are inherently more boring than variable ones and that, the interest created by variable schedules makes the learning more effective. Furthermore, this observation may be just the simplest case of a broader principle of composing sequences of a variety of reinforcers.

10.3.5 Change as a Psychological Dimension

Since Alvin Toeffler's book Future Shock was published, one of the most ubiquitous issues in the mass media has been the subject of Change. While this is usually thought of as a social or political problem, it might be instructive to study it as a psychological dimension, even as an aspect of learning. Since the computer can easily establish a situation and then alter the rules that define it in a controlled, composable way, the environment is the ideal instrument for exploring the effects of change.

10.3.5.1 The Environment Can Control Change

Once the computer has defined a particular set of relationships it can determine which parts are stable and which are volatile. Rules can be allowed to drift slowly away from their original definitions or can change in abrupt, catastrophic ways. Since the computer has provided all of the participant's input and is aware of all of his reactions, it presumably has the information needed to speculate on the state of his internal model of the environment at any given point in time. Thus, as the environment changes, the computer can infer the changes in this model from the changes in the individual's overt behavior.

10.3.5.2 Resistance to Change

Using such a tool, we can hope to discover how people react to change and exactly why some find it so upsetting. Is it somehow related to the problem of negative transfer or is there in fact a general fear of learning that always accompanies exposure to new materal? Berlitz and the Army Language Schools both assume an innate resistance to learning that must be overwhelmed by a combination of fatigue and a brainwashing, saturation exposure to the material.

Whatever the mechanism determining the reaction to change, people will differ in their awareness of change, their feelings about it, and their ability to cope with it once it is recognized. It would also be of interest to know if people need change and if so, how often they seek it. Such information would be useful in determining a manageable rate of change for each individual. If people were

classified according to their differing responses to change
it would be interesting to see if these categories were similar to the more familiar psychological dimensions.

10.3.5.3 Acculturation to a Changing World

Since we can foresee that our society will continue to change, any system of education fails that does not acculturate people to live with pleasure and satisfaction in their changing world. Perhaps, through the environment we can invent ways of teaching people favorable attitudes toward change and mechanisms for coping with it. Change seems to cause problems when it occurs in an area of a person's experience that he felt was settled, where his learning mechanism was turned off. An effort to prevent such problems should be incorporated into the original learning. It may be possible to teach people to keep testing what they have learned to see if it still obtains, and to unlearn and learn anew whenever a change is detected.

It should be possible to design games and other learning situations where the rules are in a constant state of flux and the most perceptive, adaptable person wins. Such games would equip people with strategies for learning dynamic rules. They would have to develop working hypotheses which they would be prepared to throw away as soon as they started to fail. Such an environment might move slowly from one organizing principle to another, even occasionally lapsing into total chaos. However, the alert and opportunistic player would have a decided advantage over one who continued to cling to concepts that were losing their efficicacy. There would also be a premium on being able to recognize certain kinds of change and anticipate what the new laws would be as they were coming into effect. Such games would help prepare people to deal with the long range fact of change by undergoing an analogous short-term experience.

10.3.5.4 Controlling Change

From these studies we might also learn ways of introducing changes which would alleviate the suffering it causes. Changes might be signalled as they occur. Or the participant might be given a choice of which changes occur and when they occur. A theoretical basis may be found for structuring environments so the whole seems stable even while the parts are in a state of flux. The human body is an analoguous, well-defined structure whose actual substance is constantly being exchanged for new material, whose pattern remains fixed even as all its constituents change. If such a way of structuring our environment or our understanding of it were found, we would be able to reconcile the changes we need for progress and excitement with the stability we need for sanity.

10.3.6 Biofeedback and the Internal Environment

There are two ways in which the control of body functions might be related to responsive environments. In the first approach biofeedback techniques can be used to help a person gain control of his inner states. These skills could be tested by using the vital signs as a means of navigating a visually displayed world. Or these biological quantities might be monitored while a person was moving physically, requiring him to mix inner concentration with overt action. Unfortunately, such tests can only be appreciated by accomplished yogas. A second approach would be to use the biofeedback techniques as a means of augmenting the human's communication bandwidth. Human speech normally operates at something like teletype speeds, not a very convincing argument for great intelligence. On the other hand, a much greater bandwidth might be achieved by digitizing a person's body posture or training him to modulate the muscle potentials across his back where they would be detected by a grid of electro-myographic sensors and fed into the computer. In either case the large number of parallel output channels might allow a person to communicate a picture directly. Or the environment itself might be used as an instrument of his expression where the control capabilities of his body were utilized to the fullest.

10.4 Applications in Psychotherapy

10.4.1 Introduction

It is also worth considering the application of responsive environments to Psychotherapy and the treatment of patients who are considered to be disturbed or consider themselves to be disturbed.

10.4.1.1 Therapy

Perhaps most important for a psychotherapist is the ability of the environment to evoke and expand behavior. We have found in the past that people alone in a dark room often become very playful and flamboyant--far more so than they are in almost any other situation. Since the environment is kept dark, the patient has a sense of anonymity; he can do things that he might not do otherwise. The fact that he is alone in the dark serves to protect him both from his image of himself and from his fear of other people. The darkness also is a form of sensory deprivation which might prevent a patient from withdrawing since, in a sense, there is nothing to withdraw from. Thus, if he is to receive any stimulation at all, it must be from acting within the environment. Once he acts, he can be reinforced for continuing to act.

In the event that the subject refuses to act, the environment can focus on motions so small as to be unavoidable and respond to these and as time goes by encourage them, slowly expanding them into larger behavior, ultimately leading the patient into extreme or cathartic action. This kind of release might be beneficial. If the patient feels impotent, the environment can offer him godlike control over thunderous sounds and other violent displays.

Some mental patients are considered disturbed because they do not trust people. It is the author's impression that in certain situations the therapist essentially programs himself to become mechanical and predictable, to provide a structure that the patient can accept and which then can be expanded slowly beyond that original contract. But since people are the problem, it is possible that it would be easier to get a patient to trust a mechanical environment and completely mechanized therapy. The Eliza program at MIT was originally presented as a tongue-in-cheek offering in automated therapy, but has since been taken more seriously. Assume that an environment was successful in involving the patient. Once he was acting and trusting within the environment, it would be possible to slowly phase in some elements of change, to generalize his confidence. As time went by, human images and finally, human beings, might be added. At this point, the patient could venture from his responsive womb, returning to it as often as he needed. Perhaps as time went by the environment would do things to force him out periodically. But the possibility exists that we might, if economics allowed it, permit people to avoid others this way, particularly if a way were found for these hermits to contribute to society as a whole. It may be realistic to try to define an environment which allows the patient his disturbance, adapting to him rather than asking him to adapt to the real world as we understand it.

10.4.2 Diagnosis

As suggested in the Section on psychology, the environment could also be used to study the behavior of the people within it. Arnold Ludwig, who was previously Director of Research at Mendota State Hospital in Madison and now is chairman of the Psychiatry Department at the University of Kentucky, was using a very simple responsive environment for diagnosing patients. He was not diagnosing them into the conventional categories of psychiatry; on the contrary, he was classifying people based on their responses in the environment and then asking if these categories resembled the accepted ones in any way. Thus, he could ask if people were active or exploratory and see what situations they favored.

His facility consisted of a small room with a chair in which the patient was seated. The patient was given three buttons and told he could push them as he desired. Each button represented a different kind of environment. The one button produced a complex series of flashing lights, another button corresponded to ordinary room lighting, the third corresponded to total darkness and absence of stimulation. In psychological terms, Dr. Ludwig's interest was in the range of stimulation from sensory deprivation to sensory overload, although these conditions were not fully represented by this simple first effort. He placed people in this environment and then monitored their choices of state over a long period of time to see how often they sought change or how much time they spent in each state.

This experiment is, of course, a very simple example of a responsive environment. A more general purpose tool which would allow the experimenter to explore a variety of feedback relationships could be designed. The patient could be given control of the kinds of response he received, control of what would change, and even control of the degree of control. And in this way, the experimenter might discover the aesthetics of feedback, from a psychiatric point of view.

10.5 Applications of Responsive Environments to Education

The environments have an educating effect both on their creators and on their technologically uninitiated participants; both groups are given an intimate exposure to the essence of current technology that is otherwise unavailable. In addition to the aesthetic experience the environments can be used as a vehicle for presenting specific conceptual and metaconceptual content.

10.5.1 Exposure to Technology for the Layman

The experience itself speaks most effectively to those who are beyond the reach of formal education because of their age. While few of these people would have wanted to become scientists, they have a right to learn the current and theoretical limits of Science, its short and long range implications, and a basic understanding of its language and notation.

They know that the computer has supposedly changed their lives but, although they probably will never admit it, they cannot think of any way that it has. While it may have affected large institutions and businesses to the extent that tasks once performed mechanically by people are now performed mechanically by computer, these applications touch the layman in only the most indirect administrative ways.

This misrepresentation of the computer makes those who are already alienated from technology in general suspicious of computers in particular. For most people, technology is unseen and, in fact, unseeable. The computer lurks in air conditioned offices behind glass windows and when seen is the most unsatisfying effective object ever produced. It simply does nothing perceptible. It is a humiliating experience for a layman being shown around a computer installation constantly to be asking, "Is that it? Is that it?"

Because of a lack of aptitude for math (read trivial arithmetic) recognized at an early age these people were considered lacking in the ability needed to understand the sciences and relegated to liberal arts and business courses for the rest of their educational careers. Understandably, they feel rejected and humiliated by the technological community and equally understandably they resent their own ignorance.

One modest hope is that the environment will act against this fear and anger by bringing technology into their framework, engaging them with sensation rather than jargon and mathematics, showing them that the fruits of Science can have benign, pleasurable manifestations. While making people feel at ease with technology does not necessarily lead them to a deep understanding of it, such a favorable attitude represents the minimum standard by which to judge education, for any system of education that leaves the members of a culture alienated from the instruments of that culture fails in a very important way. All that the layman absolutely has to know about technology is that while he may not understand it, he need not fear it.

The interactive environment allows the layman to directly experience advanced technology. While he may or may not like the experience, he will at least feel that he better understands what technology can do. Since, in a sense the environment is a speculation about the implications of technology, it acts as an early warning system alerting the public of possible uses and abuses before a vested interest has grown around these applications.

It would be quite reasonable to design special experiences which would demonstrate the operation of the computer visually, for by allowing the participant to interact one-on-one with a program, the environment is bringing him face to face with one of the intellectual inventions of our time. The "program" should be explicated for much the same reasons that the Renaissance Church felt the need to have painters illustrate the Bible stories for an illiterate public. But even as it allays some irrational fears and presents a certain essence concretely, the environment should convey with a sense of wonder the fact that we are all savages in our technological world. None of us understands the full implications of what we have already created and when we are confronted by the experiences in the environment, we have very little to draw on.

10.5.2 Educational Projects

Putting on these shows was an act of education in itself. Metaplay and Psychic Space were class projects put on by the author's students for credit. The course taught how to use the tools involved, discussed the possible aesthetics and introduced students from various disciplines to the process of organizing a large technical project. It gave the engineering students a chance to participate in the creation of new art rather than forcing them to analyze old art, as humantities requirements usually do. The course also gave the engineer a chance to gain practical experience with up-to-date tools: liquid crystals, light emitting diodes, television projection, video tape equipment, and computers, all very important aspects of the current industrial scene.

This practical experience produces a new kind of engineer. In the past when technology was expensive and computers cost millions of dollars, the men who used them had be be highly trained for one could simply not afford to waste computer time. Since technology was expensive, it was only owned by large institutions which hired people trained to use the tools. Thus, to prepare himself for a standard role, the student acquired a standard set of credentials and tools. Today, however, the situation has changed; the computer has become so much cheaper that it costs less than the man who programs it. These new economics open up a whole new set of possibilities, all of which must be explored if our technology is to be fully exploited. Since no large institutions can afford to conduct this much research, we will see individuals doing important research and forming small companies around each possible application. In this situation, the best credentials are a unique set of talents, insights, and prior experience. Ideally, the student has gained enough experience with the new technology to have his own ideas and make his own inventions. Thus equipped he will create a job rather than simply fill one.

For the non-technical student, this course provides painless exposure to technology. He encounters engineers, doing their engineering and learns to do a little of it very quickly. As time goes by, standardized components are making engineering design easier and easier so that in the future engineering may cease to exist. In some areas programming skill is already more appropriate than experience with linear circuits. And so the unsophisticated student may learn enough to motivate him to learn more, or, at least, to enable him to build simple devices of his own.

There is also a cultural effect for the non-technical student. In this course he is asked to consider his relationship to technology, not simply what it is, but what it could be. He is asked to ponder which forms of interaction are aesthetically pleasing and which are not. It is also suggested that the problems with our natural environment partly stem from our unwillingness to address ourselves to the aesthetic design of our artificial one. Henceforth, we will spend more and more of our lives in an unnatural setting while Nature itself becomes a pet or a parasite living on the periphery of man's activity, while adapting ecologically to the environment defined by man.

10.5.3 Teaching Environments

The responsive technology also gives us a new teaching tool which could revolutionize teaching, not by automating the classroom, but by revolutionizing what we teach. What the environment could do best would be to present non-verbal abstract material in the way of physical experience. This would be quite merciful for children who are restless and have trouble sitting still. What is actually learned would be in the spirit of the enriched environments that have been provided for infants in their cribs where they can gain a variety of early experience simply by being given many kinds of objects to manipulate. However, since the environment allows the participant to move around and the educator to control the sequence or conditions of presentation, the concept of an enriched environment can be extended to work with older children and adults. Rather than manipulating objects, the participant interacts with simple or complex feedback relationships.

We often talk quite glibly about the information explosion, but what we seldom observe is that, if there is an information explosion, there is also a concept explosion. While we have many instructors that pride themselves on teaching concepts, the time has long since passed when we should have taken education up to a higher level of generality.

We have so many concepts that their importance is reduced to the level of facts and details. We need concepts about concepts and those are what we should teach first. At some point these may well be a survey course of available concept types. These metaconcepts would reflect the ways that man likes to think, rather than actually telling anything about an objective reality. For instance, we have conservation laws because we like conservation laws, not because Nature operates that way.

The content of the medium would not come from an explicit presentation of facts or even concepts, rather it would derive from the relationships between action and response that are established during the experience. The experience would consist of discovering the relationships that were operating and then noticing the ways in which these change By seeing relationships in transition, the student would hopefully notice the possibility for relations among relations. In this way an environment could be used to teach certain important kinds of attitudes toward knowledge, learning, and change. For example, just the welter of different interactions should communicate the fact that there are many ways things might be related, many possible ways of looking at things. It should be possible to teach strategies for learning about dynamic relationships, those that change and drift as time goes by. Students would also be expected to discover general ways of structuring the relationships they find within the environment. After a period of such training even a young student would have become a creature of considerable abstract, although non-verbal, sophistication, equipped with a rich conceptual framework within which to hang specific concepts and details. Thus, the computer environments would act as preparation for more formal schooling or perhaps as an adjunct to it.

The student would know from experience that learning would always have to continue, its results constantly tested and revised. He would learn not to look for the eternally right answer but rather a temporary best answer.

Such a process is not "learning by doing" in the Dewey sense. This well-meaning phase seems to have generated nothing by exercises and menial make-work problems designed to consume the student's time. Here doing is learning--a much different emphasis. If experience is the best teacher, the environment provides a source of abstract experience that as not antecedents and may therefore be capable of teaching ideas that real experience cannot.

In addition to the teaching of very general concepts and attitudes, the environment could be used to present more specific content. It could be used to simulate dangerous or difficult situations. Even as simple a skill as crossing the street might be covered more thoroughly by a computer that has the patience to completely define it. The total feedback capability of the environment, which allows it to display physical motion as sound would be useful for teaching many physical skills from dancing to golf. A person could learn any given movement by trying to duplicate its characteristic sound sequence. It would also be useful in physical therapy and Kinesthesiology, the study of movement, which is currently forced to rely on measurements made from movie film a frame at a time since it has no high resolution real-time display of movement.

Musical instruction would be facilitated in at least two ways. First, the participant's behavior can be shaped so that it conforms to certain rhythmic conditions. Second, being forced to use his voice to control the environment, he would very quickly learn to modulate the pitch and perhaps achieve perfect pitch, now thought to be the innate gift of a few.

Certain simple concepts could be made concrete. For instance, for a child, counting could be introduced as an extension of single, double, and triple responses. One day the child would enter and the computer would give one discrete response for each act. On another occasion one act could be reversed so that three acts were required to get one response.

Sesame Street achieved considerable success with the animation of words as a means for teaching the alphabet. Within an environment, words could be animated and then made to interact with the child. In fact, it might be quite useful if he were to encounter numbers, letters, and advanced mathematical symbols as friendly playful creatures more afraid of him than the other way around. With such a background of good-will towards symbols he might never feel as intimidated by mathematics as most people do. Mathematical concepts like parameter could easily be experienced by letting some aspect of the child's behavior provide values for one of the parameters of a mathematical expression whose curve is plotted as he moves . If several children were present, each might become one of the fixed points on a least squares or interpolating polynomial. Concepts like sets could easily be expressed by drawing Venn diagrams on the floor and making walking in each domain evoke its distinctive response, whereas footsteps on the intersection would be accompanied by both.

Physical concepts like viscosity and elasticity would be represented as acting on the child's alter ego in the displayed space just as Maze sometimes enforced its boundaries by making changes in the alter ego. Spatial concepts like the transformation of one surface into another could easily be conveyed by using movement around the room to control displayed movement on the surface of a sphere, torus, or Klein bottle.

Most important, but perhaps most difficult to describe, is the use of the environment as an experiential parable. If the interaction is replete with relationships, changes in relationships, and relational ambiguity organized into a coherent whole, a sense of intellectual provocation is experienced. The result is a philosophy of events, not words. The only example produced to date is the Maze which thwarted every effort to walk it and yet used that frustration to entertain. Continuing the Maze was motivated not by the idea of reaching the goal but by a perverse curiosity about the next frustration. Since this experience could be construed as having meaning as well as interest if one were sufficiently compulsive about it, it is easy to envision people discussing the meaning of the Maze as earnestly as they might the meaning of a poem.

This domain will become better defined as more examples are composed. It is, perhaps, the most promising single area of exploration. The author has little interest in conveying explicit meaning or message but is attracted by the idea of expressing ambiguity around a central theme. Such ambiguity is an instrument of efficient communication, for while you may not have succeeded in saying one thing clearly, you have suggested several ideas at the same time. Instruction at this level has been almost completely neglected by the institutions of our culture with the exception of the churches which are using rather dated material. Certainly, such communication is worth attempting again and the environment may allow us to say things we do not already know for it is fundamentally a tool for altering our own consciousness--for teaching those who created it.

CHAPTER 11

INFLUENCE ON THE TRADITIONAL ARTS

11.1 Introduction

As mentioned earlier, the traditional art forms almost always assume a passive audience or a static display. There are a number of ways existing media could be altered to involve the audience. The performing arts, Dance and Theater, and then the verbal arts, Poetry and the Novel, will be examined to see in what ways they can be rendered interactive or even physical experiences. Finally, while several examples of responsive sculpture were described in Chapter 1, another approach which bridges the gap between object and environment will be described here. Suggestions for other forms such as graphics and music are implicit in earlier chapters and so will not be discussed further.

Before starting with the specific discussion of each form, one general observation about past applications of the computer to Art should be mentioned. In most cases the computer has been used to generate what was traditionally considered Art in each form; e.g. poems, drawing, etc. The result of a program was a piece. In a few cases the computer is being used to facilitate the artistic exploration of compositional possibilities--aesthetic design automation. Here the computer accomplishes the calculations within its scope and the human provides direction and judgment. It is the author's contention that the latter systems are in themselves more interesting than the works they produce. Vasarely has an interactive display system that allows him to visually explore many possibilities before choosing one. Just watching this tool in action is far more exciting than any one of his paintings, although the artist does not seem to have noticed this. If he had, he would have stopped producing paintings. While witnessing the output is interesting, it would be even more exciting to be in control of such a system and interacting with a universe of alternatives.

11.2 Dance

Responsive environments suggest new approaches to dance for the dancer, the audience, and the choreographer, as well as the possibility of a totally new kind of dance, not involving people at all.

11.2.1 Training Dancers

Dancers devote much of their training to trying to gain control and awareness of their body by defining new relationships to it. One part of the body may be used to lead the rest or the whole used to define a space. Attention may be focussed on the weight of each body part or on sustaining its momentum from one movement to the next. Such exercises are educational tools designed to give the dancer new ways of communicating with his own body, in the hope that these will allow him to express himself more freely.

The environment can easily define many such relationships by responding to footsteps, the movement of just one of the feet, the force of each step, posture, motion, or the distance between two dancers. Special slippers could be made to tell the computer exactly how the dancer's weight was distributed on each foot. Costumes could also be designed with colored markings on each joint and body surface, thus allowing a color video sensor to isolate the articulation of each part of the body. Auditory feedback to such details of movement might prove as important to dance as the oscilloscope is to electronics because it would allow the dancer to observe his motion even as he was executing it and hopefully to attain fine control of each action.

11.2.2 The Dancer in Control

An additional result of such feedback is a new kind of dance. In the past a dancer danced to music; he responded with motion to the patterns established by sound. The environment can reverse the process making the music respond to the dancer, so the dancer becomes an instrumental performer where the environment itself is the instrument. Visual posturing which is so important to much dance, becomes less dominant because the motion of the dancer has an effective intent, which is to control light and sound. Far from being dominated or upstaged by the technology, the dancer is in control; the environment amplifies the effect of his movement in many dimensions. Such an experience could change the dancer and his philosophy of Dance, for he has suddenly become a very powerful figure who can control all that happens around him, who in fact uses the whole space to express himself. While he can discard rigid choreography, he must consider how his dance will sound as well as how it will look. He can establish a feedback pattern on the floor and then change it just as the audience comes to expect it. He can use small parts of the floor for control functions which change the response relationships of subsequent action.

The audience cannot help but realize that such a piece is a less choreographed, less rehearsed, and therefore less mechanical performance. The motion reflects the dancer's own plans for making use of the response relationships he defined ahead of time for the floor. If there are several dancers, each can have a unique effect on the environment. While one was controlling patterns of light on the floor, another could be causing distortions of their live video image, and another causing sounds which the others were dancing to. Or, if one dancer were represented by a visual image, each of the others might be a transformation which would act more and more strongly on that image the closer they got to him. Similarly, one might be a simple tone and each of the others a form of modulation. So far it is assumed that the dancer knows what the environment has to offer. Perhaps a more interesting and more spontaneous performance would result if the dancer enters an environment he doesn't understand, explores it, discovers its secrets, reacts to them, learns about them, gains control of them, and finally learns to compose and to express himself using them. By the end, what was a threatening external environment has become an extension of the dancer. Appreciating such dances would require a completely different attitude on the part of the audience which could not expect a finished and slickly choreographed piece, but rather intelligent and graceful behavior in an unknown situation.

11.2.3 Involving the Audience

The audience could also become more actively involved. If they were seated within a conventional theater, the seats could be bugged so the inevitable shifting in their seats is sensed by the computer. These movements could be translated into sounds to which the dancer would respond. Thus, the stirrings of a passive member of the audience make him an active element in the dance. Or, the audience could be given conscious control of the feedback relationships. By defining active areas of the stage, response modes, and background lighting patterns, the godlike audience could manipulate the dancer according to their whim. Whether putting it in these terms makes it seem unattractive is not important, the possibility exists--and might represent a powerful experience.

11.2.4 Applications to Choreography

There are many ways the new technology can alter the choreographer's task. Using a graphic display he could simulate many aspects of his work without involving live dancers. Once he had satisfied himself with the simulated composition, the computer could generate a series of instructions for each dancer. After these instructions were translated into an auditory code representing the intended movement in great detail, these signals would be transmitted to the earphones worn by each dancer to guide him through the movements in real-time. Before dancers could become radio-controlled marionettes, they would have to master the choreographer's encoding scheme, but once this was accomplished, a new piece could be blocked out relatively quickly without as much repetitive rehearsal.

The choreographer could also use responsive relationships to emphasize the movements of his dancers during their performance. If the stage were covered with the graphic floor described in Chapter 7, patterns of light could be made to dance around the dancer. Or if a perspective defining display such as the one used in Glowflow or the one to be titled Space Dance described in Chapter 7 were employed, the space itself could appear to dance around the dancer. Or, if a number of rearview video projection screens were arranged in an arc around the back of the stage, not only would the dancer appear to be surrounded by his own live image, but the perspective from which each of these images was taken could also be moving around the dancer. Or, finally the large numbers of laser beams could automatically track his movement so he would appear to be the center of a radiating web of light. If a number of different colored beams were used with each color following a different body part, the result would be a breath-taking undulation of swirling light.

11.2.5 Pseudo Dance

Finally the computer would permit the definition of a totally new kind of dance, one that does not involve people at all. A computer could generate it's own figures, its own graphically defined entities and then articulate and animate them. Elastic limbs, disconnected or nebulous bodies, and liquid movement are all easily attainable. In Russia there is a proposal to physically realize a number of cybernetic animals which would move in graceful ways suitable for ballets. They would inhabit a large mechanical menagerie where they could interact with human visitors. Through such means Dance can be generalized to be more than just the interesting and graceful movement of the human body, by exploring the dancing of mechanical, imaginary, or even impossible bodies to see which ones would be most interesting in their dancing motions. Also, by combining these computer images with the participant's video image, real and imaginary creatures can dance together.

11.3 Applications to Theater

11.3.1 Proscenium Theater

Responsive technology can be applied to traditional theater; or the concept of theater can be expanded to include the responsive environment itself.

In proscenium theater the possibilities are somewhat limited but nevertheless interesting. Each actor's movements could be followed by distinctive light or sound responses which would directly enhance the characterization and become part of the character's identity. If the feedback relationship were to change, this occurrence would be noticed by the audience as a dramatic event, focussing their attention on the moment. When several actors were on the stage, the differences in the feedback which accompanied their actions would serve to accentuate the differences in their personalities or dramatic function.

11.3.2 Audience Participation

More interesting are the ways that responsive technology can be used to involve the audience. Past efforts to involve spectators have usually failed because the format of traditional theater includes a passive audience, a fixed script, and an isolated stage, thus allowing very little room for audience participation. Simply the existence of an identifiable cast and audience makes it very difficult for the onlookers to overcome their traditional passive role. As long as the physical separation is maintained, a way of involving the audience without them knowing is needed. Again, as with dance, the seats can be wired with sensors so the squirming of each person in his seat provides signals to be detected by the computer. If these signals were translated into sound or light events, the actors could talk about these events, weaving them into the dialogue and perhaps reinforcing the person for making these sounds. Ultimately, the individual will realize that it is he who is being talked about and finally, he who has become a character in the play. At this point it might be desirable to switch control to another seat.

The author has used this technique when describing his environment to a group of people who were seated on the floor within it. By focussing the computer's attention on a small part of the floor, and reinforcing movements sensed by the floor with simple sound responses, he was able to get one individual rocking back and forth without being aware of it. After a while his motions became so extreme that everyone else noticed that he was not only moving in an exaggerated way, but that it was he who was responsible for the sounds they were hearing. At this point the computer was focussed on another part of the floor and another group of people were involved in creating the sound. Soon the entire audience was crawling around trying to create sounds, trying to find the active part of the environment. What had started as a staunchly passive audience became something quite different. In fact, the audience had ceased to be an audience, thus ending the talk.

If the audience of a play were seated on an open space like the floor and disbanded by the responsive technique just described, it would be an effective way of ending the play or part of it. The audience would know that the scene was over when they discovered that the scene was over when they discovered that they had ceased to act like an audience. The audience could be reconvened, forced back into their passive role, only the application of assertive acting, lighting, and musical techniques. Actors in the audience could act as part of it during the responsive period and then establish a dialogue among themselves which would slowly be recognized as a continuation of the scripted play which might oscillate back and forth between the structure of the script and the disorder of a spontaneous audience.

Each member of the audience could be given explicit control of his own perception of a play. If several related scenes were acted out simultaneously on the stages, the audience could not follow all the action, particularly if all the dialogue were carried on in very muted tones which could only be picked up by microphones distributed around the stage. All of these sound signals would be available to each member of the audience through a special audio selection system which would allow him to listen in on what was happening on only one part of the stage at a time. Each person would see the overall gross motions that make up the play, but could not get complete auditory information about parts of it. Each individual would have to actively investigate what was happening, continually judge which scene was most important, and thus become involved in the production in a totally new way. This relationship places additional burdens on the playwright, the actors, and the director, for they must create a play wherein the eavesdropping audience can get a feeling for the characters and events depicted. Each member of the audience, on the other hand, could choose to follow the action in any way he liked, concentrating on one character or one scene hoping that his choice would lead to an understanding of the play.

11.3.3 Distributed Theater

One exciting possibility is that the actors no longer need to be in the same physical space. It is feasible to create a geographically distributed theater in a video space composed of video images from widely separated sources superimposed to form a single image. Each actor would enter in this video space through his local camera much the same as people enter a room through different doors. Images could interact visually and to some extent physically, depending on the sensing system available. The audience cannot "really" see the action because the action does not "really" exist. The actors would be interacting solely by means of the technology. This sort of theater would perhaps be most interesting where there was a mixture of real and media scenes. Here the question would always exist, "Is this event happening in video space or real space?" The audience would constantly be making a choice whether to really see the play minus some of the principle actors or to see it well via television much as reporters covering political conventions end up watching them on television, even though they are physically there.

This new theater could be designed to involve people physically, since action could occur in a number of different places and yet be tied together or partially tied together in a video space. It could also be done in such a way that not all of the information was available through the video medium, so the audience would have to wander through the physical space in which the action was unfolding and try to learn as much as possible about what was happening, or even to affect what was going on.

11.3.4 An Acting Audience

It would also be interesting to blur the distinction between the actors and the audience. The only definition of an actor would be someone who, willingly or not, acts in a way that is inappropriate to a person not involved in the play. Similarly, in traditional theater an actor is one who is willing to come out on stage and act as if there are not hundreds of people watching him.

The spectator might unwittingly become an actor in a completely unforeseen way; the computer could watch his movement around the theater space through a television camera. It would store a series of poses and postures required of the actor in a certain role. The goal of its surveillance would be to collect video images of the participant in all these poses so they could be used to make him appear to perform in the video space.

The movements of his image would be similar to the partial animation techniques associated with television cartoons like the Flintstones. Even with such limited movements it should be a disturbing experience for the participant to see his image given a life of its own. Such an effect is possible today, given the right aggregation of hardwares: although to the best of the author's knowledge, the partial animation of live images has not been suggested before.

11.3.5 Responsive Environments as Theater

It can be seen that the next step in this direction and away from conventional theater would be the author's responsive environments. These are theater where where there is no audience, i.e., no passive onlookers, and no actors who come onstage knowing exactly what they are going to do for the duration of the show. All the traditional relationships are gone, but what is left is an automated happening, a theatrical situation where the participant is responsible for his own experience.

11.4 Influence on Poetry

11.4.1 Kinetic Poetry

Poetry remains a determinedly static form, untouched by the development of Kinetic media. Some attempts have been made to extend poetry into other forms. Concrete poetry, for instance, makes the shape that the poem assumes on the page part of the art form. It's odd, however, that in a day when film is probably the most accepted contemporary art form, little has been done to animate the visual representation of poetry as is done in film credits, which often make inventive use of words in motion. It seems lamentable that no poet has seriously taken up the idea of expressing himself through the animation of words, for such an extension of Poetry seems like a very reasonable experiment.

A program written on the LINC (a small laboratory computer with a graphic display) by Tom McFarland, one of the author's students, provides an example of a simple first step. The letters of a single word were defined as a series of points, each with its own speed and direction associated with it. As long as all the points have the same speed and direction the word will move slowly across the screen. Upon reaching the edge of the screen the word was reflected point by point so that it was folded back on itself. After four such rebounds the word was restored to its original left to right form. After a minute or so of this, the letters that made up the word would start to drift away from the path that the word itself had been taking. Finally, all of the points on the screen started going in completely different directions. This explosion of the letters was not at all violent, but more like fluff blowing off a dandelion seen in slow motion. The rebounds from the edges were also a very sensitive motion. In general the author feels that such slow movements and transitions are more sensual than the rapid activity in most computer film.

This program suggests a whole new attack for poetry. Essentially poetry could become a form of dance. The words and the letters would constantly be in a state of flux, moving about the screen juxtaposing with other words, transforming themselves into new words, picking up new letters, and disbanding--in ways limited only by the imagination of the programmer poet. A sequence of such interactions would constitute a poem.

11.4.2 Interactive Poetry

This kind of poetry has one disadvantage that is not as pronounced in the traditional form. Existing poetry is unique among written forms in that it is not necessarily experienced in a linear way. True, words are written down on the page in a fixed order, but as one reads and rereads a poem the tendency is to jump around in it to better appreciate the relationships which are defined. Unfortunately, an animated poem, like any film would start at the beginning and progress inexorably to the end. Therefore, it would be desirable to maintain the participation of the reader by making the poem interactive. The reader would enter into a relationship with these words, which would become entities moving about the screen, each with their own rules of behavior. These rules would be based on the aesthetic desire of the poet and the words themselves. The reader, who is no longer a reader, but a participant, might most appropriately be represented as a word himself as he chooses to involve himself in this environment of living words.

By now, it must be transparent to someone reading this paper that the next step is to suggest that this form of poetry not be confined to a graphic display screen, but rather become the basis for an environmental experience. Graphic words and computer generated word sounds could move around the walls, floor, and ceiling interacting with the participant or a representation of him. By switching speakers rapidly, the origin of the sound could go completely around the room during the enunciation of a single word. Or, if a real-time holographic projection system were available, the word could approach the participant as an apparently freestanding object. Words displayed on the lighted floor described in Chapter 7 can follow the participant or be chased by him. His footsteps can leave letters on the floor which assemble themselves into words that are spoken by the computer when he steps on them. While the effects just described are trivial, the author is confident that powerful, poetic statements could be made once the facility existed and there was time to explore its capabilities.

Allowing a word to interact physically with the participant is a symbolic statement, for the word is no longer a vehicle for communicating meaning but a behaving entity of its own. Given the impact of television and film and the likelihood that computers will shortly be able to speak and understand speech, the written word may be obviated. Thus, it seems appropriate to give it life, allow it to leave the page, interact with the man who wrote it and leave the scene.

11.5 Writing

11.5.1 The Traditional Consistent Novel

An interactive novel may seem a little far-fetched. But the idea is intriguing, even potentially practical. The simplest novel relates a single ordered sequence of events. The author may employ various strategems for breaking through the rigid linear sequence of the time in which history supposedly takes place, he may follow parallel threads which contribute to the understanding of a larger span of events, he may jump around in time as Vonnegut does in Slaughterhouse Five, but ultimately he has to yield to another form of time when he writes his book, the reader's time. Each reader will read his book starting on Page One and continuing page by page until the end.

The writer typically starts with a provocative set of circumstances and a rich cast of characters. From this wealth of possibilities he selects a set of consistent events, and reveals them in any order he chooses. Many interesting possibilities must therefore be lost. Sometimes the reader wonders what would have happened if a certain event had not occurred.

Since a novel is currently published as a book, it's very unnatural to try to define anything other than a story that is to be read from one end to the other. It would be awkward to define the branch points in the story where the reader chooses among alternative paths in the story; plus, since any given reader will pursue only a few of the paths, most of the paper will be wasted. However, if somebody were to write a story that did not have to exist as a physical object it might be natural to structure it much differently.

11.5.2 Alternative Story Paths

The computer provides just such a flexible means of dealing with the text. There would be no difficulty in writing a story which was not a string of events but a web of possible mutually exclusive events which could be experienced through an alphanumeric display terminal. There would be a number of possible paths through the story, each representing alternative developments or perhaps different perspectives on the same events as in the Alexandrian Quartet. The reader would not exhaustively follow all paths, but would explore only those that interested him. In a mystery story he coud act as detective, checking the separate narratives of each character to see what they knew at any given point in time. Or, he could follow a path until something happened he did not like, back up, and follow an alternate path where the disagreeable event had not occurred. The author could also provide all sorts or background material on the characters and situation which the reader could delve into if he wished. Extraneous asides like Thackery's or historical philosophizing like Tolstoy's in War and Peace would be optional. The re...er could pursue them at the point in the story where they had occurred to the author or continue the narration without their interruption.

11.5.3 Mystery Novel Writer

The author worked briefly with Sheldon Klein, a professor at the Computer Science Department at Wisconsin, on a program to write mystery novels. In this system a simple parlor game called "Murder" was modelled. Once a number of people and their behavior patterns were defined, the model was allowed to run until one of the well motivated characters killed another. At this point a detective entered and questioned each of the characters to try to determine who had committed the crime.No one could lie except the murderer. If the detective was unable to determine who had comitted the crime, he would simply leave and the characters would resume interaction until the murderer killed again. There were algorithms for translating each of the modelled events into the English text. The final product was to be a book, although the intent was not to produce literature, but rather to explore a problem in linguistics: how to get the computer to talk about what it knows.

11.5.4 Interactive Novel

This author would prefer not to produce a finished book, but to allow the reader to read the story as the computer generated it, to say, "I didn't like what just happened. Go back and make it unhappen. Then let's do something else." The author would design models of situations together with a basic set of characters. The reader then could read as the computer manipulated the model. He could not only cancel events but also kick out characters he did not like and add new ones from the author's repertoire. Unlikely interactions between usually exclusive stereotypes such as cowboys and frogmen could be allowed. If these options seem childlike, the computer's current linguistic abilities are perhaps best suited for a child audience. Writing for children would provide an added benefit. Since the computer selects the words it uses to generate the story, it would be possible to introduce vocabulary at a controlled rate.

The computer could also generate graphic images to illustrate the story as it is generated. At some point the story generator can become the basis for an environmental experience where the participant becomes the protagonist.

11.6 Responsive Sculpture

Although several works of responsive sculpture were described in Chapter 1, the example offered here bridges the gap between a responsive art object and a responsive environment, thus developing an option that has so far been overlooked. The physical sculpture which will be executed by Joan Sonnanburg, one of the author's past students, will be a reclining female nude cast in fiberglass. Like any other sensual sculpture this one is bound to tempt an occasional furtive touch. However, unlike the others, it will respond to that touch with a protesting squeal or an accepting sigh. As he succumbs to his curiosity, the viewer will discover that each part of the body controls a different kind of response. Initially, the responses will emanate exclusively from the figure, but later they will involve control of all light and sound sensation in the space. From the first, the viewer must contend with the conflict between his embarrassment about touching and his desire to know the power of the figure.

11.7 Conclusion

While the most important effect of responsive technology on the Arts will be the creation of interactive environments, all of the other art forms will be touched in varying degrees. Equally important, each of the established media will suggest form and content for the interactive artist. Hopefully, though, the emphasis in all Art will be less on the passive appreciation of the work of a sensitive few and more on evoking an active expression of such sentiment in all.

CHAPTER 12

CYBERNETIC LIVING

During the balance of this century, responsive technology will move ever closer to us until it becomes the standard interface through which we will gain much of our experience, interceding in our personal relationships and between us and our tools. The appearance of isolated devices such as calculators and two way cable in our homes augurs the knitting together of a single integrated interactive network which we will encounter through every effective device in our environment.

12.1 Responsive Technology at Work

While there are a number of ways responsive technology will influence our offices and factories, only a few non-obvious applications will be described here.

12.1.1 Acting at a Distance

While the central theme of responsive environments is communication between man and machine, they also provide a general tool for communicating from one place to another. It is commonly recognized that communication and transportation are at least partially interchangeable. Recent changes in the economics of energy suggest that this substitution should be formally explored. As mentioned in the first chapter we have already gone some distance in allowing men to act through remote control. What we must now ask is how much must be communicated before the need to travel is eliminated. A natural motivation for much of today's practical travel is simply the need for a manager to see what is going on at a remote plant site. He can meet the principal people in the flesh, seek information, and gain impressions. Such an inspection might be accomplished by remote control.

Initially, a T.V. cameraman could walk around the site transmitting whatever the remote viewer asked to see. This cameraman would receive his instructions in the form of audio signals through earphones. The signals would indicate whether the camera should hold, pan left or right, up or down, zoom, physically approach or recede. The observer, who might be a thousand miles away, would interact with a video monitor a series of simple controls, and a voice system allowing him to query those encountered by the cameraman. The cameraman could later be replaced by a robot which might even sport a video display of the teleparticipant so those at the scene could see who they were dealing with.

Such a system would have limitations, of course. If the observer were checking the manufacture of artificial fabrics, he would still be unable to feel them, although the transmission of tactile information is currently being researched.[1] The confinement of the display screen could be avoided by placing stereo-video receivers in a set of goggles for the viewer to wear. Then the physical movements of his head and body within his space could automatically direct the movement of the robot and the aiming of its camera.

12.1.2 Video Place

The Video Place concept described in Chapter 7 would allow widely separated people to convene for a visual conference which would lack little as a substitute considering the rigid structure of such gatherings. Each man's image would be merged into a virtual image too large for the display screen. Each person would then control his own window selecting from the virtual image those people he wanted to look at.

The hardware system used in Metaplay which included such a capability was used with practical intent. While testing the transmission of position data generated by the floor sensors, we displayed the waveforms sent on the PDP-12 in the gallery and those received on the Adage in the Computer Center. The video images of these two displays were overlayed and available at both ends as were the voices of those involved. The composite image also included the hands of those at either end as they pointed out the salient features in the signals. Oddly, care was always taken not to overlap the images of the different hands--i.e. not to touch. The unspoken etiquette inspired the idea of "Video Touch" suggested in Chapter 6. What was important about this example was the fact that there was utterly no temptation to go from one place to the other; for the requirements of this application, communication was complete.

12.1.3 Interaction and the Structure of Knowledge

In the future our relationship with knowledge will change. More information will be accessed through display terminals and less through hard copy. We may have our own soft copies of what we read, complete with marginalia and underlinings as well as individual information systems structured to personal needs.

Most important will be the effect of random access on the presentation of organized knowledge. The central task in writing a book is defining a single hierarchical structure that covers most of the author's ideas and then imposing a linear ordering of that structure on the network of associations which would more fully convey his thoughts. A more natural approach might be to use the computer to write a large number of packets several paragraphs long, each covering a single idea and potentially associated with all of the other packets. The strongest associations and therefore the most natural transitions would require a few sentences to make the connection between packets. Upon completion of each packet, the reader could select which branch he would follow based on his background and interests rather than any single arbitrary structure which must necessarily obscure the associations natural to many of the readers. The network of associations would include all structures suggested by the information.

12.1.4 Enriching Repetitive Tasks

It is commonly observed that mass production which has refined each task to optimal efficiency has thereby impoverished the worker's experience by not providing enough variation to keep him interested. In many cases a human is used for a function only because it is not yet possible for a machine to do the job as cheaply and, as Samuel Butler observed, "When a man competes with a slave, he becomes a slave".[2]

It would seem that there would be ways responsive technology could be used to enliven such work, perhaps by providing the kind of rhythm used to make life bearable for galley slaves or marching soldiers, by giving some sense of community. Feedback generated by the task could be reinforcing, although it might intensify the boredom if the relationships were unchanging. On the other hand, if the response could be varied, a way might be found to make repetitive work interesting, not for itself but for the feedback that accompanied it. Then each repetition might be approached with curiosity about what its consequences would be. Throughout the day as the feedback relationships developed and unfolded, the worker would have the feeling he was getting somewhere.

12.1.5 Personal Expression Through Repetitive Work

Suppose the sounds responding to a worker's movements were not only available to him, but could also be heard by others so they would know what he was doing just by listening. Even better, if he were to define the feedback relations himself, he could express himself while he worked. Even within a well-defined movement, there are variations of articulation, speed and pressure available to the human body which don't conflict with the task and might provide as many degrees of freedom as a piano keyboard. Thus, each person could declare his individuality, even as he and his co-workers performed identical tasks. Alternatively, the workers could weave their feedback together, jamming on the job.

Another function which would benefit by enriched feedback is typing. The typist performs the same basic task, striking the keys, endlessly. With an electric typewriter it would be easy to have an annunciator that would emit a different sound for each key as it was struck. Such feedback would be a useful training device, providing a student with information about what he had typed without looking at the result. It would also allow a manager to monitor the typist's progress. If each secretary were allowed to define her own sounds, a typing pool might emit the murmer of highly individual voices rather than the consistent rattle of today.

12.1.6 Putting Labor Back into Work

Technology has solved one problem all too well. It has all but succeeded in eliminating labor, i.e. physical exertion from all parts of our lives, but especially from our employment. However, because our bodies require physical exertion for health, we face the irony of an extra hour devoted to exercise after we get home from work. Since our labor saving devices have in this sense lengthened rather than shortened our working day, we must find ways to reintroduce physical effort into our jobs so we at least get paid while satisfying these undesired needs of our bodies. A way must be found to make conceptual tasks physically strenuous. A typewriter that operated by punching and kicking (figure 12-1) might not type as fast as the usual kind but by maintaining the health of a valuable person while allowing him to perform a useful task its output might indeed be greater.

12.1.7 Total Immersion Problem Solving

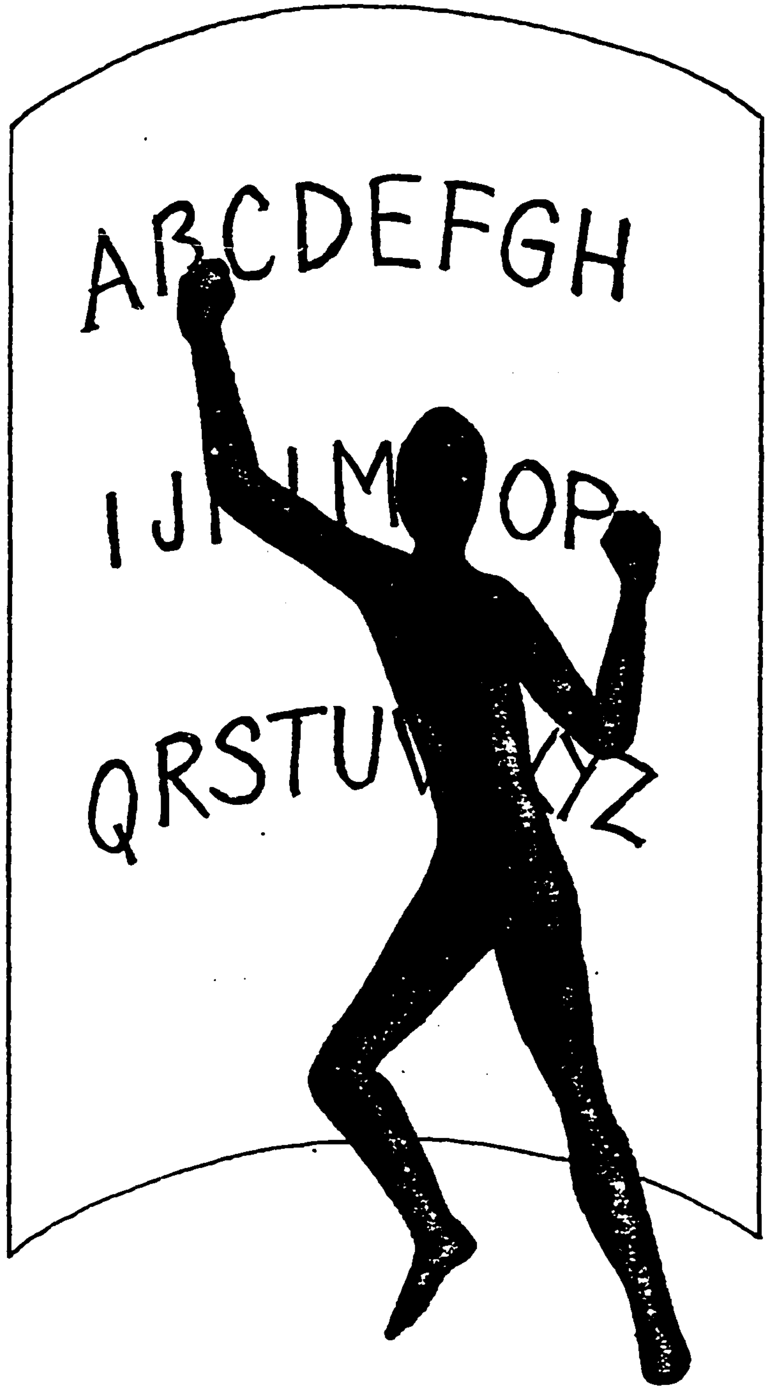
The tendency toward ever richer representation of problems and proposed solutions may lead the definition of problems of such complexity that they can only be attacked by the total physical as well as intellectual involvement of the problem solver who may have to effectively live in the represented world. Each day would be spent exploring the problem space learning about it, and physically seeking a solution.

12.2 Leisure

Responsive technology also will affect our instruments and rituals of pleasure. Idle games, competitive sports, musical instruments, and sex could all be heavily influenced by an electronic interface.

12.2.1 Games in the Responsive Environment

A whole family of games could be based on the responsive environment. A shooting gallery where the participant shoots out lights which turn



Kung Fu Typewriter

fig. 12-1

on all around him with a photosensitive gun would be a simple first step. The same idea could be extended so a number of children, each wearing a light could shoot it out. Less bloodthirsty and more interesting would be games of chase and agility based on the graphic floor described earlier.

The only commercially successful responsive environments to date have been the pin ball machines which still suffer from a limited repertoire of control functions, i.e. either buttons or knobs. Using a keyboard, photocells, or a television camera as means of control the player could participate in the game in a much more effective way than the standard two buttons allow.

12.2.2 Exercise

When one must get exercise apart from the job, there are ways the computer could be used to make it more interesting. Techniques very much like those suggested for assembly line work could keep a person working out longer. The computer could provide light and sound reinforcement as long as a given level of performance is maintained. For example, pedaling a stationary bicycle could generate the electricity needed to power a television.

Exercise could be turned into a game between exerciser and machine. For instance if a laser were mounted above a large open space and provided with deflection system capable of aiming the beam anywhere in the space, the individual could chase the beam. When the beam was caught with his photocell transmitter, its position would be changed. The score would be based on the number of times the beam was caught within a fixed amount of time. This game could be adjusted to make the beam easier or harder to catch. Any game played against the computer could be adjusted in this way.

12.2.3 Sports

Organized sports could also be invented which would take advantage of the new technology. If a laser beam were directed into an empty room occupied by two teams of four men each, hand held mirrors could be used to deflect the beam toward the opponents' goal. A series of photocells around the reflector would tell the computer when the reflector moved so the beam could track it, thus allowing a man to run with the beam. While a number of deflections might be required to reach the goal, the team would gain score until the opposition succeeded in breaking the beam either by stealing it or by knocking down one of the players establishing the path.

Robots might also be used in sports. Today's automatic tennis ball thrower could evolve into a machine capable of playing the game. Again its ability to reach the ball and the strength and placement of its return might all be adjustable, allowing the player to have an opponent of comparable skill. Remotely controlled robots could play against each other giving the armchair quarterback a new dimension in vicarious excitement.

12.2.4 Musical Instruments

To date the control of most musical instruments has been directly determined by the mechanical system producing the sound. Piano keys cause hammers to strike metal wires. The fingers are used to stop the holes on a flute or oboe. With electronic instruments, however, the means of control are completely independent of the means of sound generation. Thus, for the first time the only constraint on the keyboard system is the human body. Each control system may well have its own distinctive sounds, its own range of possibilities. Many of the sensing systems described earlier would be suitable. The video outline sensor or a series of strain gauges around the body would be versatile, although a compact keyboard like the accordian's might be more so. It is worth pointing out that the design of the ultimate keyboard is exactly the same problem posed in Section 10.3.6, "Increasing the Human Bandwidth."

12.2.5 Intimate Technology

Even man's most intimate communication might be mediated by the computer. The Japanese have already suggested the transmission of sexual data between lovers. What has not been considered is that such transmissions would free a person from the usual constraints of his body, allowing him to touch another as if he had more than two hands, etc. He could set in motion one sequence of ministrations to be carried out automatically without further attention while he focussed on more intricate details. The means of orchestrating such stimulation might be a keyboard instead of a body and the possibility of sexual concerts more real than quixotic.

12.3 Responsive Environs

The trend has already started for every effective object in our environment to be capable of perceiving its surroundings so it can perform its function as needed rather than waiting for instructions. Feedback will also be designed to attract people's attention and control their behavior if possible. Finally, responsive displays will be used as a decorative art form, initially exciting and reassuring to the pedestrian, but ultimately reaching the impotence of responsive muzak.

12.3.1 Artificial Entity

As the economics become favorable, men will be tempted to give the appearance of life and the ability of expression to their most important possessions. The prime candidates are the car and the home. It's long been recognized that many people view their car as an expression of themselves. This is somewhat surprising since in its current manifestation the car is a very limited means of expression, confined to a single statement made at the time of purchase and repeated less and less strongly as the car ages. After that the car is dumb except for the horn and perhaps a coat of wax. There are times when it would be desirable to be able to express the more immediate feelings of the driver, e.g. his embarrassment when he inadvertantly cuts someone off, or his annoyance when the situation is reversed. If the car were painted with an electroluminscent phosphor, the whole car could be made to blush or turn livid. If the phosphors were driven by the car's generator, its color would change as the car accelerated.[3] Colors could also be contingent on the direction the car was headed or the vibrations from the road. Within, the car could be a little more tactful when reminding the passengers to buckle their seatbelts. It could also provide supporting feedback about road conditions, oncoming cars, or erratic driving which might indicate an inattentive driver.

Even more elaborate will be the interaction between a house and its occupants. There are already enough control functions needed in a house to justify a central processor to coordinate them all. The heating, hot water, cooling, security, laundry, cooking, intercom, lighting, and entertainment systems all contain separate control functions which could be vastly expanded with a minimum of hardware.

Almost certainly, the house will be given a voice with which to greet the family or scare intruders. It will mediate much of the business that goes on within, reassuring the child who awakes in the night, even perhaps allowing the parent to monitor a sleeping child while out for the evening. Possibly one baby-sitter could watch a hundred sleeping children over closed circuit television, thus freeing their parents to do more with their evenings.

As this artificial presence becomes more convincing it will become a member of the family although some people will demand social conventions whereby robots answering the phone identify themselves as such, just as margarine was prevented from imitating butter for years. These voices will spead to us in elevators, pedestrian crossings, self-service restaurants, and gas stations. The words will be simple at first but the messages will grow ever more intelligent.

12.3.2 Advertising

Responsive techniques might prove very effective in gaining and holding a pedestrian's attention at a shopping mall. An ad could gain attention with one display and when the computer sensed that interest was flagging, switch to another. Initially, just the presence of responsive display controlled from the sidewalk would attract a crowd of onlookers.

12.3.3 Architecture

Both the design of future buildings and the appearance of existing ones can be dramatically affected by responsive technology, perhaps challenging our basic concept about what a building is.

12.3.3.1 Design

Perhaps the most sophisticated interactive programs existing are those aiding architects and city planners. These systems allow free conceptual design while the computer keeps track of the practical constraints and alerts the user when these have been violated.[4] Architects no longer look on their function as static design, programming a solution to a given request for a building. Rather they see themselves as pre-experiencing the building--an exciting redefinition of their task.[5] Ivan Sutherland at the University of Utah has designed a system that allows a designer to view a space in three dimensions through stereoscopic viewers and by turning his head look around inside of it.[6] There is also a program called City, which allows the architect or city planner, to drive through the planned or proposed design.[7] He sees it, not as a flat blueprint, but as an apparently three-dimensional sketch of the city. Weaknesses in the design are easily encountered through realistic experience during the design process. They can be easily changed since they are not yet cast in concrete. The modelled building could be peopled by simulated creatures programmed to search for the most glaring errors and complain to their creator about what they find. It is easy to envision such cooperation between real and simulated entities becoming ever more complex and fruitful as the distinction between real and artificial becomes even more arbitrary.

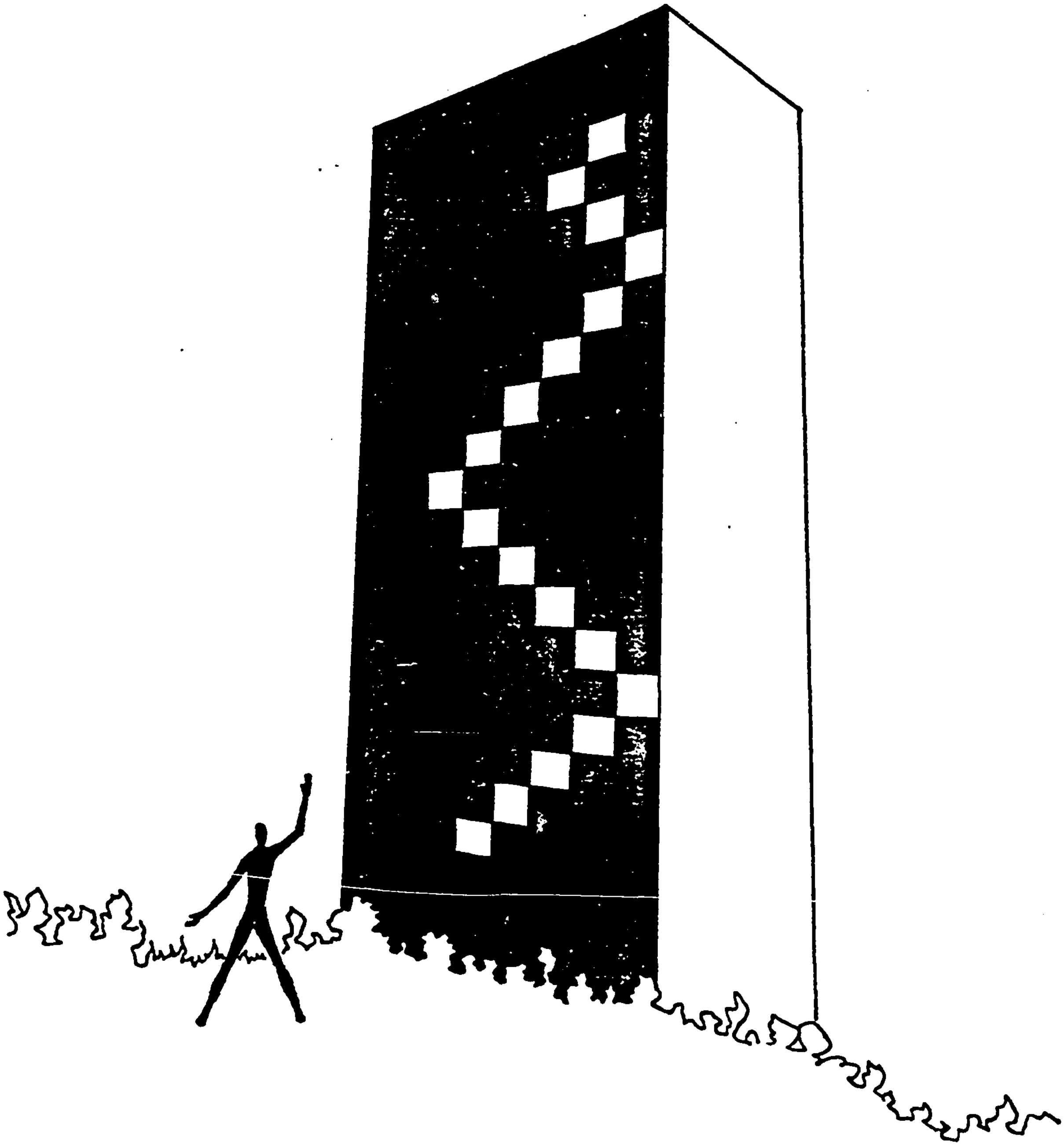
12.3.3.2 Inside Existing Buildings

Practical construction problems have led us to create buildings with some of the most sterile interiors imaginable. The evenly lighted, endless tunnels found in airports and apartment buildings provide an unbroken monotony so rigid as to be upsetting. There are ways that the tedium of the physical space could be relieved by defining an alternative visual space within it. Abraham Rothblatt a onetime Madison artist now living in Philadelphia, uses tape applied to the floor, walls, and ceiling of an existing space to define another, often ambiguous visual space within it. Using electroluminescent tape such a display could be made dynamic, allowing the same boring hallway to appear to be different each day. The patterns could change in response to those who move through them, perhaps leading them to their room. With a powerful display system visual organisms could be defined that would effectively haunt the building's corridors, making them seem a little more lively even when empty. Each species might have its own habits either seeking or avoiding people according to its nature.

These displays might be static much of the time but occasionally involve two strangers about to encounter each other in a mini-happening. While people are often apprehensive in such a situation, they would be brought together in this case because for the moment they would be sharing a theatrical event that occurred solely because they both were there.

12.3.3.3 Outside Existing Buildings

Next to mountains, buildings are perhaps the most static objects in our environment. The only exception to this rule are those whose surfaces are completely consumed with the need to advertise. In Las Vegas the buildings have been completely transformed into animated signs whose primary function is simple communication. As usual, the Twentieth Century idea of communication is one-way broadcast or dissemination rather than interactive dialogue. The last example is the proposal that a large building be made to acknowledge people below and yield to their control. Van Hise Hall, the building depicted in figure 12-2 would be appropriate because it is a large monolithic structure with one window per office. By controlling the fluorescent lights in each office the exterior of the building could be used as a giant display. A television image of a person standing on the Hill across the street would be used as input. As he waved at the building, it would wave back, his movements controlling the patterns that flowed over its surface. Technology would thus be used to expand the power



Participant controls Van Hise

fig. 12-2

of the individual rather than leaving him powerless before it.

12.4 Conclusion

The examples given in this chapter represent only a few of the infinite number of possibilities which may be realized. Some of the examples have been deliberately trivial because our future life-style will no longer be characterized by the few economically compelling applications but rather permeated by a welter of ancillary applications implemented simply because they are pleasing.

CONCLUSION

The work described in this dissertation is a personal affirmation of Technology espousing a humanism which accepts it as part of Nature. Technology presents us with a near infinite set of possibilities which we must explore for the same reason we climb mountains--because they are there.

For the past century humanists have viewed Technology as a pernicious force beyond their control--all the more intolerable because of its human origins. The work described in the preceding chapters insists that the effectiveness of a work of art is strongest at the time of its creation and weakens in its antiquity. An artistic work that requires a scholar's footnotes cannot be considered more powerful than one that speaks to its audience directly. The common assumption that fifty years hindsight is required for the identification of a work of art is based on a lack of confidence, denies the value of art in the present and makes aesthetic judgment a kind of historic Neilson Rating. This attitude goes back to the worship of the Greeks by the Romans. It is anti-Art. The young are taught to appreciate past Art much as physicians expose people to a weakened form of a virus so they will become immune to the real thing.

However the author's primary goal is not the creation of Art. His motivations do not really spring from the Art and Technology movement which demands that the technique be subordinated to the aesthetic. Rather, the author seeks an expression of Technology itself, an aesthetic statement of the majority faith in Technology, Science and Human Invention. A need for this statement exists because even though we live in an overwhelmingly technological culture, traditional artists have been almost unanimously hostile towards Technology.

With the cost of computers plummeting a new age of invention is incipient. New horizons will appear in every direction much as if ten new continents were discovered simultaneously. The result will not only be new artifacts and new activities but also new concepts and new culture. The author can glimpse fragments of this future and can sense how rich and unexpected it will be. In his work he seeks to convey the essence of this vision, to make it concrete, as a painter would try to capture a landscape.

The future which the author envisions is one that many say we should avoid. Indeed to continue as we have brings us to a discontinuity. We are beginning to violate a host of old taboos: creating artificial organs, exploring space, manipulating genes and perhaps understanding and artificially duplicating the mind. We are stripping ourselves of whole layers of mythology. Not only has Nature as a godlike force been all but banished from this planet, but we now find ourselves acquiring powers once reserved for the gods. We find ourselves not the final goal of evolution but now its conscious agents.

There is no denying that this future will change what we are and how we think of ourselves. However, we cannot let fear of our own capabilities cause us to bury our talent. It is as idolatrous to fear the Golden Calf as it is to worship it. We must continue and like Nietzchean Supermen allow ourselves to be constantly redefined by our own actions and creations.

One theme of this thesis is that the future need not be approached so somberly . In our actual experience of the future these epic issues will be background and day to day events paramount. To fully explore and enjoy what we are about to create will take more than practical problem solving. To truly master our tools we will have to use them for aesthetic expression, whimsy and play. We must do this if we are to discover what it is, that what we have, made makes us.

FOOTNOTES

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