Designing in Virtual Space

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ABSTRACT

Design is described as consisting of visual thinking processes which modem computer-aided design interfaces fail to exploit. An ideal design interface is postulated leading to the concept that virtual space can be used as a design medium. Recent advances in technologies to synthesize virtual worlds are discussed The concept of a virtual terminal is presented with speculations regarding its application to design and other uses.

I. INTRODUCTION

Humans are visual beings. When we pick up the newspaper and turn to the editorial section. our attention seems to be drawn immediately to the political cartoon. In a matter of seconds a message (albeit largely symbolic) is communicated to us. Describing the same information in a word picture would require a time-consuming conversion from written symbols (words) to the mental picture that they would elicit. From infancy we learn to deal with spatial things. in the way that we perceive objects in three-dimensional space and interact with our world. Our sense of vision enables us to orient ourselves in space, control our posture and provide other cues for locomotion and communication.

It can be conjectured that much of our analytical processing is also visual. As we read (largely a left brain function), we transform these word symbols of our language into mental images to which we can more easily relate. Speech also engenders the same mental imagery. Often as one speaker describes his own mental image. the listener is creating one of his own. (These two mental images may not match. which is often the root of communication problems.) Even mathematical concepts and numerical data often are more effectively communicated using visual means (e.g.. graphs) than words. Visual thinking allows us to deal with magnitudes. dimensions. or properties associated with physical things. The purposes of this paper are twofold: the first is to explore some factors associated with visual thinking in design tasks; and the second, to postulate a set of tools for enhancing the design of physical systems.

II. VISUAL THINKERS

Many of our civilization's most accomplished scientists have attributed their successes to observation and thinking. McKim (1980) observes that Sir Alexander Fleming turned a laboratory accident into the discovery of penicillin by his thinking about what he observed. In this case, Fleming noticed in a routine laboratory experiment that some plate cultures of staphylococci had apparently become contaminated and died. This observation had most likely been made by others who knew that some bacteria can interfere with the growth of others. but Fleming saw it in a way that eventually led to the discovery of penicillin. Nobel laureate James D. Watson (1968) also attributes his discovery of the construction of the DNA molecule to the use of a three-dimensional physical model. He stated:

Only a little encouragement was needed to get the final soldering accomplished in the next couple of hours. The brightly shining metal plates were then immediately used to make a model in which for the first time all the DNA components were present. In about an hour, I had arranged the atoms in positions which satisfied both the X-ray data and the laws of stereochemistry. The resulting helix was right-handed with the two chains running in opposite directions.

Henzon (1985) adds that even Albert Einstein's primary mode of thought was not words or mathematical symbols. He quoted the following passage from a letter by Albert Einstein:

The psychical entities which seem to serve as elements in Designing in Virtual Space 129 thought are certain signs and more or less clear images which can be "voluntarily" reproduced and combined....The above mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will.

Benzon concludes that Einstein "thought in images and then translated those image-born insights into verbal or mathematical form." From these examples, we can better appreciate the role of visual thinking in the creative process.

III. WHAT IS VISUAL THINKING?

It has often been stated that we do not see objects, we see images. Indeed the rays of light which impinge on our retinae are converted into electrcochemical impulses which, traveling through various waypoints, finally arrive at our visual cortex. Our sensation of the light rays occurs at that point, and the spatial distribution of light constructs an image in our heads to which we may associate some meaning. But we can also construct an image in our heads with our eyes closed This "imagined image" can have the spatial attributes of anything that we "see" in the world. Still, there is a third kind of visual image which we can create through our own psychomotor functions. Imagine that you are standing in front of a chalkboard (formerly a blackboard) and holding a piece of chalk in your hand. Now, pretend to draw a triangle on the board by physically moving your hand. Now picture in your mind the triangle you have drawn. This third category of visual imagery can thus be connected to psychomotor functioning (i.e., moving your hand to conform to your mental image of a triangle). The process of drawing with a pencil on a pad is also a translation of a visual image into a physical one using this psychomotor connection. In this same regard, visual images can be formed from purely tactile stimuli as depicted by the following:

Six wise men of India
An elephant did find
And carefully they felt its shape
(For all of them were blind).

The first he felt towards the tusk,
'It does to appear,
This marvel of an elephant
Is very like a spear.

The second sensed the creature's side
Extended flat and tall.
Ahari." he cried and did conclude
This animal's a wall;

The third had reached towards a leg
And said, 'It's clear to me
What we should all have instead
This creature's like a tree.

The fourth had come upon the trunk
Which he did seize and shake,
Quoth he. This so-called elephant
Is really just a snake

The fifth had felt the creature's ear
And fingers o'er it ran,
I have the answer. never fear,
The creature's like a fan'.'

The sixth had come upon the tail
As blindly he did grope,
'~t my conviction now prevail
This creature's like a rope.

And so these men of missing sight
Each argued loud and long
Though each was partly in the right
They all were in the wrong.

(Quoted from Hampden-Turner, 1981)

This "illustration" of the blind men depicts three processes related to the science of design and vision. The first is that the observer always adds to his sensory stimuli (in this case. touch) a meaning which is built on his own experience. We seem to be always filling in the blanks, often based upon limited stimuli (such as viewing a house partially hidden by trees or piecing together a jigsaw puzzle). We still recognize the object as a house and even make assumptions about its size and shape by extrapolating from what we see. The second point is that even touch conjures spatial interpretation. We construct a visual object in our mind's eve to correlate with the object we have touched. Thirdly, most scientific description (and design'.) can be approached from different points of view Our ability to communicate is largely a function of understanding various perspectives

IV. THREE KINDS OF VISUAL THINKING

It can be concluded from the discussion above that there are three kinds of visual thinking: ~) the kind that we see from objects in the world; 2) the kind that we imagine, such as visual imaging while reading a book; and 3) the kind that we create ourselves when we write or draw. Humans (who are not blind) have various skills related to the interaction of these kinds of visual thinking. An illustrator for example may be effective at representing that seen in graphic form, whereas an artist may be more able to translate an abstract imagining to a canvas that conveys meaning in a symbolic way. Both examples require interactions between the kinds of visual thinking. Perhaps all three kinds of visual thinking interplay when one brings his own reorganization or interpretation of something that is seen, such as trying to draw the structural members which support a building by only observing the outside of the building. Figure 1 is a symbolic representation of the three kinds of visual thinking discussed above. The creative process is most fully promoted when all three visual/psychomotor (kinesthetic) processes are active as shown by the overlapping region of the diagram. For some reason, the visual imagery can be strengthened when the efferents from the psychomotor activity are mixed with the afferents from the visual observation. (This may be what Einstein referred to as the "muscular type" of interaction.) Perhaps many of the problems which we have with design can be attributed to failure in the interplay of the three kinds of visual thinking. In our enlightened civilization, new design mediums should be developed to overcome these breakdowns.

V. COMPUTER-AIDED DESIGN

The process of design can be thought of as forming a plan to organize or reorganize matter to carry out some purpose, usually that of changing some state in the designer's world. This changing of state may be to provide vehicles of conveyance for transporting individuals or other matter from one place in space to another, or to prevent others from conveying matter from one place to another (in the military realm), or just increasing our understanding about things. Design may also deal with the way that information is acquired, manipulated, and represented. Regardless, design is mostly visual Modern digital computing technology has provided us with marvelous tools for acquiring, processing, and storing information. More than ever before, the computer has the potential to extend the intellectual power of the human, but the degree to which computers can serve as tools depends largely on the quality of its interface with a human. Current methods of interfacing using cathode-ray tube (CRT) terminals and keyboards (and mice/light pens, etc.) restrict the flow of information and commands between the computer and the operator. Users are required to structure and channel communication to fit the programming languages of the machine. In turn, the computer portrays information in a highly coded form in two-dimensional space. Although natural language interfaces, once developed, will probably improve the flow of information from the human to the computer, these technologies do not increase remarkably the useful "bandwidth" of the interface and unlock the power of the combined intelligences and computing capabilities of the human/machine interface. The key to solving these problems is to make the machine more "human-like" rather than requiring the human to be more "machine-like." In view of the visual thinking capabilities of the human, computing systems are especially limited. Although computer-aided design systems have facilitated design by allowing rapid "drafting" and perspective modeling of objects, the ultimate natural visual thinking capabilities of the human are not tapped because the existing interfaces do not enable the three kinds of visual thinking described above.

VI. A THOUGHT-CONTROLLED MATTER MANIPULATOR

Perhaps the best hypothetical tool a designer could have would be the means to translate his thought images instantly into physical realities with which he could interact using his other visual and psychomotor functions. Such a tool might be called a Thought-Controlled Matter Manipulator. Assume that by picturing an object in the mind's eye, this matter manipulator would organize matter in such a way as to cause a three-dimensional physical copy of the imagined object to be created in reel time. The designer in this case could reach out and touch the object, bold it, turn it, and perhaps even operate it, given imagined functions for the object to perform. The idealized use of all three forms of visual thinking (i.e., seeing, thinking, and psychomotor) would be exercised. The designer could then easily modify the design by "rethinking" and watching those changes materialize before his eyes. Our Thought-Controlled Matter Manipulator could also be connected to various data base "assistants', which would augment the knowledge of the designer. For example, if information regarding population physical anthropometry, materials science, and human information processing were accessible to the designer, the object of design could be manipulated with machine help to conform to the attributes of many users. Perhaps the designer would want to look at the object through the "eyes" of his specialists. In this regard, he would place in front of his eyes "specialist's spectacles" which would allow him to look at the object of design from the standpoint of his assistants. Human engineering spectacles would help him to consider the structure of the design so that it can be used by the 5th to 95th percentile of male and female populations or so that the dynamic tracking capability of the human provides sufficient precision for its operation. Structural engineering spectacles may point out the stresses, strengths, and types of materials which can be used to manufacture the object. Cost and reliability spectacles tell him he has to start over with the whole design. Although hypothetical, the Thought-Controlled Matter Manipulator embodies the attributes of an ideal design tool. It truly makes the best coupling between the head' eyes, and hands of the designer in order to organize and manipulate matter in space. A more realistic alternative to this approach is to create a display medium in which synthesized images produce the same visual perceptions as physical objects.

VII. DEFINING VIRTUAL SPACE

The visual space which surrounds us can be thought of as a volume of infinitesimal luminous elements. These elements are the "atoms" of our visual world. The size of each element is equivalent to the limiting angular resolution of the eye. In a spherical coordinate system, the orientation of each element is a function of its angular coordinates relative to the head and eyes. The perceived depth or distance of an element from the eyes is generally a function of the differences in location of the light that each element makes on the retina of each eye (i.e., retinal disparity). Size, convergence, accommodation, and parallax cues also contribute to the perception of depth. With these angular and depth coordinates, the dimensional properties of visual space elements can be described. The luminous properties of each element can also be described using measures of radiance (e.g., hue, saturation, and luminance). The visual image of every physical object can then be described by an array of visual space elements (Hochberg, 1986).

Suppose that a device were inserted into the visual field that projected onto the retina a synthesized distribution of light rays equivalent to each element in our visual space. With the proper organization of the synthesized light rays, the sensations produced in the visual Cortex would simulate those coming from a physical (three-dimensional) object. This synthesized image would then act as a surrogate" for the original object (Hochberg, 1986). The image which is formed by our device is called a "virtual" image. Accordingly, the visual space occupied by virtual images is termed "virtual space." Although in virtual space a physical object does not exist, the perception of the virtual image is the same as if it does exist. Furthermore, if the instantaneous vantage point of the eyes relative to the synthesized object changes, the distribution of light in the virtual space can also be changed to reflect the new vantage point (thereby creating parallax cues). Such a virtual display could produce the same visual images as the Thought-Controlled Matter Manipulator (but they would represent non- physical objects).

VIII. A BASIC VIRTUAL WORLD GENERATOR

Figure 2 shows a system of functional components for producing three- dimensional "surrogate imagery" for the operator. A similar system was proposed by Sutherland (1968). The key to the system is special headgear which produces points of light on miniature television picture tubes (CRTs) and projects these light rays through optics into the eyes of the operator. The operator then perceives a virtual picture composed of the light points which appears in space in the direction of his gaze. Although the pictures are produced in miniature on the CRTs, they are magnified and projected into the eyes so that they appear as large scenes at optical infinity (i.e., they are collimated). This projected scene acts as a "window" into the larger virtual space. The window is positioned as the operator moves his head. The size of this window is a function of the instantaneous field of view of the optical elements which project the CRT images into the eyes. Since there are independent channels for each eye, retinal disparities can be produced to create a sensation of depth. The original virtual space scenes are synthesized in a programmable graphics processor and input into the binocular display electronics where the signals are produced to create images on the CRTS. The instantaneous orientation of the head-aimed optical system, and hence the display window, is measured by a magnetic tracking system. These signals, in turn, are fed to the graphics generator so that new scenes are continuously recreated to compensate for head movement In this way, the pictures are stabilized in virtual space or appear to have a fixed location relative to the observer. Since the head can also translate in virtual space, six degrees of freedom must be measured to properly position the synthesized images in virtual space. In addition to the head-mounted unit shown in Figure 2, a hand-mounted unit is also used to interact with the virtual space objects. The hand-mounted position trackers measure the instantaneous position and orientation of the hands in three-dimensional space. These signals are also input into the virtual space generator causing images of the hands to be displayed in correspondence to their true position relative to the virtual objects being generated. As the operator's hand comes into "virtual" contact with the virtual images, vibro-tactile simulators provide a sensation of "touch" feedback Although the virtual object produced by the virtual display system above have no mass, the visual and some kinesthetic sensations are equivalent to the idealized Thought-Controlled Matter Manipulator discussed earlier. The virtual hand tracker can also be used in reverse to "draw" three dimensional virtual objects which appear as physical entities in front of the operator. This interaction with the virtual world is facilitated by adding to the basic virtual world generator figure 2) an eye line-of-sight measuring device and speech recognition controller as shown in Figure 3. Now the designer ca move or alter virtual objects by giving verbal commands while simultaneously touching or looking at the objects within the world.

IX. CREATING IN A VIRTUAL WORLD

The essence of the machine in Figure 3 is to produce a circumambience of "virtual matter" which the designer can use interactively to create new design.

The virtual world produced by this system becomes a cognitive input/output port between the human and the machine to promote a more effective matching of the spatial skills of the human with the computing, graphics, and data base management power of the computer. It is in this virtual domain where the human and the computer "live" together. This space can be thought of as being like a visual "living room" in which computer-generated objects or symbols appear (as three-dimensional virtual images) to the designer as if they were physical realities. The designer can look around the room (~g., the furniture, etc.) and reach out and "touch" these virtual objects. The operator can also translate within the computer-generated world by physically walking around in the "virtual room" If the optical system used to project the light rays from the miniature CRTs are made transparent to the outside, or reel world, the designer's world can be superimposed over the real world. Thus, an empty reel room can be filled with virtual furniture. Doorways can be moved, windows replaced, and carpet installed with the movement of the hands while drawing upon a virtual data base "catalog" of home furnishings. Consider the application of the MacPaint or MacDraw programs for the Apple MacIntosh as shown in Figure 4. Used with a conventional two dimensional terminal, it is necessary to compress a three-dimensional world into two dimensions. Perspective drawings convey a sense of depth, but true dimensional spatial interaction is limited because the objects of design cannot be touched. Using the concept of Macpaint/MacDraw with a virtual terminal allows the designer to create a true three-dimensional virtual object, which can be realistically portrayed as it would exist as a real object. In order to create a virtual object, the operator would view an empty virtual space surrounded by icons and a virtual hand as depicted in Figure 4. He selects a mode by speaking a command (such as "plane"), or picking up an icon with his hand or eye (by looking at it). He then positions and orients his hand in space and speaks the word "stay." The virtual world generator then provides the signals to draw a representation of a three-dimensional plane in space. The operator then adds shading/color by picking up a virtual paint brush or spray can and virtually paints his plane. Many planes or surfaces of rotation are drawn the same way. Intersections and boundaries are shown. He can then change or smooth the corners of the object by saying "smooth" while moving his hand over the object, carefully shaving away the virtual matter to produce an object which has the desired contours. The operator can scale the design instantly by saying "zoom." He can walk around the object and see from different sides or views. By pushing the design with his hand and commanding "move," he can translate or rotate the object in space or group it with other objects so designed. Commanding "combine" causes the combination of designs to be treated as one object. Functional operations can also be assigned to the objects of design. For example, gear wheels with adjustable ratios will turn with each other. A virtual clock movement (the old kind without quartz and liquid crystals) can be designed and toured in virtual space. Figure 5 is a further refinement of the viral world generators in Figures 3 and 4 to provide a virtual space design system In the specialized design application of the virtual world, data bases are added such as those described initially in the Thought-Controlled Matter Manipulator. Upon command by the operator, information from the data bases can be accessed and portrayed graphically or used to modify the designs in virtual space. The "Designer's Associate" is a machine aid to guide the design process and assist the designer in accessing the data bases. The characteristics of this associate will be discussed later.

X. MINDWARE

In his article on "The Visual Mind and the MacIntosh," Benzon (1985) discusses how a relatively simple computing machine has become a tool for the visual brain. Even though the MacIntosh has made inroads into user friendliness, the real breakthrough comes from the software, such as MacPaint, which provides the "visual power." The interface of the human with the virtual medium can be thought to exist in "direct" and "indirect" forms. The direct forms are those which are physical or involve the transfer of light, sound, or mechanical energy between the operator and the machine. The indirect pathways are the internal models that the operator develops regarding an understanding of the machine and its capabilities (and for that matter, the machine has about the operator). These models cause the data represented on the display to have meaning or "semantic content," that is, the level of meaning or information derived that can be associated with the data elements on the display. The direct pathways are concerned with the control and display of the virtual world. The indirect pathways are concerned with the composition of the machine intelligences that implement the cognitive port between the human and the machine. Both the direct and indirect pathways are important in communicating understanding between the human and the machine, and both require the development of new classes of software. The software to implement the direct pathway is straightforward. In this case, virtual space is considered to be a three-dimensional volume to be bit- mapped. As objects are created in virtual space, the allocation and selection of these bits to portray the world must be computed. The solid geometric relationships based upon viewing perspective must be manipulated rapidly to provide a dynamic real-time portrayal of virtual objects. Computing algorithms will involve coordinate transformation matrices manipulated by array processors. The direct pathway software will also provide "drafting tools" for use in virtual space. This tool kit gives the designer a variety of graphical paint brushes, magnifying glasses, color pallets, sunlight, and functional associations (e.g., causing an object to obey a set of preprogrammed functions or movements) for use during the design process. The indirect pathway software is more complex. As it pert- to the things which are going on in the designer's head, it can be appropriately called "mindware." Mindware assumes that there is a level of intelligence in the machine which understands to some degree the design problem and the intent of the designer. The mindware synthesizes the quality and personality of an "associate" for the designer. The associate first insures that both the machine and the designer agree on the perception of the problem, and then (gently) guides the design process, recommending design considerations as changes in the situation dictate, to achieve an efficient and successful solution to the problem. It is through this interface that the machine infers the intent of the designer, thereby allowing the machine to assist in accessing data and

knowledge bases as shown in Figure 5. The mindware also implements a form of "symbolic communication" between the designer and the associate through the medium of the virtual world. Symbolic communication provides a nonverbal two-way communication channel, allowing the system and the designer to signal understanding and intent to each other with simple integrated symbology that minimizes operator cognitive effort. The software functions by sensing and processing behavioral sequences to deduce current information needs of the operator. It also includes the delivery of the information via a communication architecture and display formats that capture relevant spatial relationships in an easily understandable form. This use of machine intelligence significantly extends the intellectual capacity of the designer by allowing the vastness of design data bases to be accessed in a friendly and expeditious way for refining the object of design.

XI. MAKING VIRTUAL DESIGNING A REALITY

Several concepts and machines have been developed over the last 20 years to explore the use of virtual space as a design medium. Sutherland (1963) describes perhaps one of the earliest using a binocular helmet-mounted display and head position trackers. Later, demonstrations of this work were also made (e.g., Sutherland, 1968). Krueger, Gionfriddo, and Hinrichsen (1985) also describe an "artificial reality" which serves as a visual medium through which the operator can interact with a graphics system . Termed "Videoplace," the authors have created a visual scene which includes a computer-generated silhouette of the operator and symbols projected simultaneously on a screen. The operator moves or interacts with the computer-generated symbols by the way he moves in the room and positions his limbs. The authors state that this artificial reality can be learned readily and used as a tool to interact in different ways with the computer. In 1977, the Air Force's Armstrong Aerospace Medical Research Laboratory began a project to develop a virtual space simulator (Kocian, 1977). The impetus for this project was to provide an engineering research tool to investigate the portrayal of information in modern military aircraft The basic design of the system was achieved by significantly extending the performance of previously developed helmet-mounted tracking and display systems (Furness, 1978). Designated the Visually~oupled Airborne Systems Simulator, or VCASS, the system became operational' in 1982 and since has sparked a revolution in the design of crew stations and simulators ~urness, 1985; Mills, 1985; "Virtual Cockpit's Panoramic Displays," 1985). Currendy, different versions of the VCASS are being developed for airborne crew stations (i.e., virtual cockpit), spacesuit applications; visual performance test battery; connnand, control, communication; and computer-aided design ~urness & Kocian, 1986). Furness and Kocian (1986) indicate that several psychophysical studies have been conducted with the VCASS, investigating the portrayal and interaction of information in virtual space, and that user responseVisually-Coupledwhelmingly positive. Head, eye, voice, and hand control interactions within virtual space have also been demonstrated.

XII. APPLICATIONS

Perhaps one of the most obvious applications of the virtual design terminal is for the design of crew stations. Such a design tool allows the cockpit designer to create a virtual work station which can (in real time) be manipulated and operated to perform intended functions. These prototypes may represent a conventional "physical type" cockpit using panel-mounted displays or the more advanced "virtual cockpit," wherein all cockpit information is portrayed in three-dimensional virtual space. Such a facility is rapidly reconfigurable to relate to any mission. When used with a terrain data base and computer-generated imagery system, the designer can become the pilot in a simulated operation of the crew station in a hypothetical vehicle (aircraft/tank/ automobile). Visibility outside the vehicle can be adjusted based upon the pretended size of the occupant (from the anthropometric data base). In essence, the human can be scaled relative to the system to see what it looks like if he were smaller or larger. In the case of an aircraft cockpit, the designer would select the parameters of information to be portrayed, indicate where the display is to be located, then fly the vehicle using that portrayal. In the process of design, other data bases can be accessed to investigate human factors, materials, and other physiological design considerations. In all cases, the design session would be assisted by the Designer's Associate. In this application, the associate would guide the designer by asking questions: "Have you considered-..? if not, here are some factors that should be taken into account." Other designers, consultants, or operators can be called into the design process. They too would be provided with a design terminal and able to react to the virtual crew station and add their recommendations. (1t should be noted that the designers do not necessarily have to be in the same location; they could communicate designs through a modem.) At the conclusion of a design session, the design information would then be translated to punctilious dimensional drawings for manufacture. The virtual space design system could also serve as tool to train designers and students of many visually oriented disciplines. Electronic engineering students can visually ride upon an electron while transversing the silicon space of an integrated circuit. A physicist could tour a virtual room of molecular structures synthesized from an X-ray diffraction machine. Indeed, he could reach out and touch the atoms within a crystal lattice, making adjustments and noting changes in the bonding energies. (James D. Watson would especially appreciate this application.) An entomologist, looking through the eyes of a scanning electron microscope, could take a tour of the eye of an insect, probing its structures while he walked around in a virtual room (while virtually connected to a scanning electron microscope). Electronic engineering students could study field theory by actually visualizing the three-dimensional nature of the electric and magnetic fields induced by the movement of charge in conductors or in space. The power of the visual image and psychomotor interaction can transform the teaching of advanced concepts to students wherein a virtual three-dimensional medium can be used- Even abstract mathematical concepts can come alive in visual space as the manipulation of equations changes the nature of n-dimensional space. One of the most provocative applications of a virtual world system has been described as the "Knoesphere" (Lenat, Borning, McDonald, Taylor, & Weyer, 1984). Here the authors describe a scenario using equipment similar to that described in Figure 5, but with the additional feature of an expert system with encyclopedic knowledge. In this article, the reader is taken on a hypothetical tour through the data base subject of his choice, wherein the data is transformed into a "museum." The participant is assisted by an electronic guide whose personality and professional background are selectable. The participant can also adjust the perspective of his tour by using "spectacles" which

filter Out or stress various features of the tour to be taken. With these a priori adjustments, the knowledge base is unfolded as a museum tour, guided by the electronic personality. The authors speculate that the eventual impact of the Knoesphere will be on education, where not only facts can be presented, but principles. taught.

XIII. CONCLUSION

There is something magic about being able to see and touch things. It brings a spatial reality to our consciousness. It is in our mindscape that we truly manipulate matter using our sight and touch as interfacers. Allowing the human and computer to relate spatially in a three-dimensional world opens vast new possibilities for improving crew stations, computer-aided design, and instructional systems.

The challenge of the future is to develop the "soft things" which program the new virtual interface mediums described in this paper.

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