Using High-Bandwidth Input/Output in Interactive Art

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B.Sc. Computer Science, University of Ottawa, Canada, 1991.
B.F.A. University of Ottawa, Canada, 1997.

Submitted to the program of Media Arts and Sciences,
School of Architecture and Planning,
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Abstract

Are we making the best use of commonly available high-bandwidth input/output(I/O) devices on our computers? How would research on this subject be affected if it were driven by a purely artistic mandate?

The bandwidth in question refers specifically to video input and output devices, the only high-bandwidth devices that are on found on common, conventional computers. Under normal circumstances, these devices transmit moving two-dimensional images at rapid refresh rates; this high-bandwidth is a prerequisite for the capturing and viewing of motion images. A great potential exists in using this high-throughput capacity in applications that do not simply convey continuous moving images. In the burgeoning field of highly technological interactive art, a large number of works suffer from poorly adapted interface mechanisms. New high-bandwidth I/O configurations can serve to derive improved interfaces for the creation of interactive art.

This course of research is not driven solely by the desire to create new technology and improved modes of interaction. As the the infusion of rapid-changing technology in art reaches popular levels, the role of the artist in society is equally in flux. The definition of such a role is sought as part of this thesis.

These goals are accomplished through the study of the nature and history of interactivity in art, the development of new prototypes, the creation and exhibition of interactive art works in public spaces, and through a close analysis of the role of the artist-scientist in contemporary society.

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1 Introduction

> *A man sets himself the task of drawing the world. As the years pass, he fills the empty spaces with images of provinces and kingdoms, mountains, bays, ships, islands, fish, houses, and people. Just before he dies, he discovers that the patient labyrinth of lines traces the image of his own face.*[0]
>
> Borges

As so eloquently stated time and again by Borges, our lives and our culture are an endless amalgamation of intertwined mazes and labyrinths. Boundless and complex, with no lens wide enough to bring it all into focus, it is a grey mosaic held together by occasional yet elusive instances of clarity.

Borges could be suggesting that an artist can function as a conduit for painting the picture of humanity, and that we will do so by painting our own selves, because this, honestly, is all we have to draw upon. Art, therefore, fulfills its function best not when it imitates, or when it acts as an anonymous conduit, but when it is most honest, when the work is the closest reflection of what is truly unique about the person who created it.

The story of my culmination at the doorstep of MIT is a common one; that of a free spirit looking for a singular voice. The duality of my preceding life having become untenable; on one hand pursuing a stable, lucrative role as an information technology worker, on the other an open-ended investigation in the form of a contemporary art practice in sculpture and installation. I surmised that if there were to be a place where these entities could merge, then surely, it would be at the Media Lab.

But is there really anything new about the application of technological and artistic knowledge toward a single goal. History would tend to indicate otherwise; Leonardo da Vinci makes an exemplary case in point. In a world massively specialized through the profound and prolonged after effects of the enlightenment, the industrial revolution, and market globalization there would seem to be no place in the world for a Leonardo today. Yet the disorienting, divisive, and dehumanizing regiment imposed by the rigors of contemporary existence paint a picture of a world that could benefit from the all-encompassing vision of renaissance thought.

0 Borges, Jorges Luis, *A Personal Anthology*, Grove Press, New York, 1967, p. 148.

One remarkable aspect of Media Lab is the degree of freedom bestowed upon its research staff. During my tenure here, I've had the luxury of not concerning myself with the question of whether what I was doing was art or technological research. The bottom line, simply stated, is to be thorough and create original, thoughtful results, worthy of discussion and of further investigation. The categorization of the work is not always clear; sometimes the result will find its way into industry, on other occasions it will find its way into an art gallery. What is critical is that the focus remains purely on the quality of the work and not its place in the global economy, whether it be the mass market or the art market.

As a result of articulating this last point, I've been accused of conducting an insular existence, of living inside a bubble, far removed from the real world. As a counterpoint, I present the results of my efforts at the Media Lab over the past 18 months and in doing so propose a *modus operandi* where no contradiction exists between the functions of artist and scientist.

In support of this premise, this thesis presents both technological research and artistic production in an integrated format. The thread that binds is the focus on interactive art that makes use of high-bandwidth input/output techniques; thus the title. This entails the investigation of new technologies and the creation of prototypes as well as completed art works.

If it is true that all stories can be expressed in the form of a labyrinth, then I propose a labyrinth that draws its course through the history of humanity and leads to the consolidated practice of the artist-scientist on the eve of a new millennium.

1.1 Central Issues Addressed by this Thesis

The primary issue addressed by this thesis is: *is it possible for an individual to perform simultaneously the functions of artist and scientist in contemporary society?* This issue is examined through a study of historical precedents, through the creation of technological prototypes, through the creation of art works that use this technology, and through the investigation of current environments in private and public institutions that do or can foster the role of artist/scientist.

The second central issue addressed by this thesis, which is nested within the first, asks the question: *what reconfigurations of existing high-bandwidth input and output devices on general purpose computers are conducive to improving the expressive capabilities of technology?* This issue is addressed with focus on video input and video output devices which constitute the only high-bandwidth devices commonly present on conventional computers. This issue is pursued with a more traditional scientific approach, where prototypes are designed, developed, tested and analyzed. Ultimately, successful prototypes are integrated into completed works of art, serving the primary issue of this thesis.

1.2 Thesis Structure

This thesis is structured as follows: A foundation for research, development and critical discussion is established in the first section, where the history of interactive art is traced through general art history. The works discussed in this section are chosen for two primary reasons, the first they serve to illustrate the lineage of interactive art, and secondly, the examples present the art-science dichotomy from a unique perspective.

The next section provides a detailed description of prototypes and completed works. Work is presented with a background of preceding relevant work. The development process of each item is presented in detail as well as a functional description, and a discussion of the objectives involved, the issues that were addressed, and how they succeeded or failed. All installations, prototypes and software described herein were created by the author unless explicitly stated otherwise.

The subsequent section categorizes and analyzes the work produced. It defines a course for the future. Issues central to this thesis are then cast into a wider context of contemporary art practice, technological research and global culture in an attempt to define a field of operation for the contemporary artist/scientist.

3 Context

3.1 Early Beginnings

To claim that interactivity is a recent innovation in art is misleading to say the least. Since the dawn of civilization, art forms have sought to create a dialogue with their subjects, and this can be viewed as the basis of interactivity in all art.

Figure1: Hall of Bulls, Lascaux , France 13,000BC.

In this section, examples of art over the course of history will be discussed in an attempt to outline the lineage of what could be called the contemporary practice of art and technology which commonly manifests itself as interactive installation.

To find the a very early example, we look at the paintings and carvings of the Lascaux caverns in southern France. It was in these caverns that the most outstanding examples of prehistoric art were found in 1940. Some 15,000 years ago, deep inside these caverns, sometimes hundreds of yards, well beyond any spaces used for habitation, hunter-artists carved and sculpted images of animals. They used natural ochers in a medium that was perhaps animal fat using bristles as brushes and large bones as palettes. Specially crafted stones were used to make the thousand or so engravings that adorn this site.

The remoteness of the paintings and the engravings suggests their viewing was associated with a ritualistic activity and that they were thought to hold magical powers. The haphazard layout and layering of the paintings indicates that they were done over extended periods by various artists, but interestingly, great caution was given to the area where two images overlapped. Although the apparent haphazardness of the layout has not been fully explained, it has been established that these sites were used in ritualistic activities.

One theory suggests that the apparent randomness in the layout becomes rational through the use of lighting effects during the rituals. Much in the same way that lighting works in a theatrical setting, the master of the ceremony creates a narrative by shifting focus from one image to another in a specific sequence, perhaps with a vocal and/or dance accompaniment. This theory further explains the presence of sharp gouges in the paintings being a result of viewers engaged in throwing spears at the walls in the heat of what may have been a frenzied ritual. Here we see the appearance of the first interactive art works.

It seems absurd to draw comparisons between paleolithic caves and high-tech computer installations, yet the similarities are uncanny. These isolated environments with light controlled imagery and tangible manipulatives providing interaction with abstracted representations of real phenomena foreshadow the the existence of modern virtual reality systems used in medicine, flight simulation, games and, of course, interactive art. But what is truly remarkable here is the use of abstraction, as observed by Lacroix, Tansey and Kirkpatrick:

> *It is significant that the miracle of abstraction-the creation of image and symbol-should take place in such secret and magical caverns. Abstraction is represent tation, a human device of fundamental power, by which not only art, but ultimately science comes into existence. Both art and science are methods for the control of the human experience and the mastery of the environment. And that was the end-purpose of the hunter-magicians to control the world of the beasts they hunted.*[1]

In this statement, we observe that the fundamental kinship between the practices of art and science lies in the use of abstraction. Later in history, a rift will form between these two, alternately referred to as the art-technology dichotomy. Before moving on to the next example which is from Greek antiquity, it is worth pointing out that the words art and technology both originate from the Greek word “techne.”

The Lascaux cavern configuration immediately brings to mind another well known cave, a mythological one described in the Plato’s *Republic*. Here it exists only as a purely abstract concept used as an elaborate metaphor of the human spirit, known as *Plato’s cave*. In it, human subjects are restrained such that they can only see shadows reflecting on the wall directly in front of them. The light source is a fire that burns behind them, in front of which the intellectual elite create shadow theatre to control the intellect of the restrained subjects. The only reality known by these prisoners is a shadow on the wall. Behind them is a tunnel that leads to sunlight and to a higher morality, but they do not know about it.

1 KirkPatrick, Diane, De La Croix, Horst, Tansey, Richard G., *Gardner’s Art Through the Ages*, Harcourt Brace Jovanovich, Orlando, 1991.

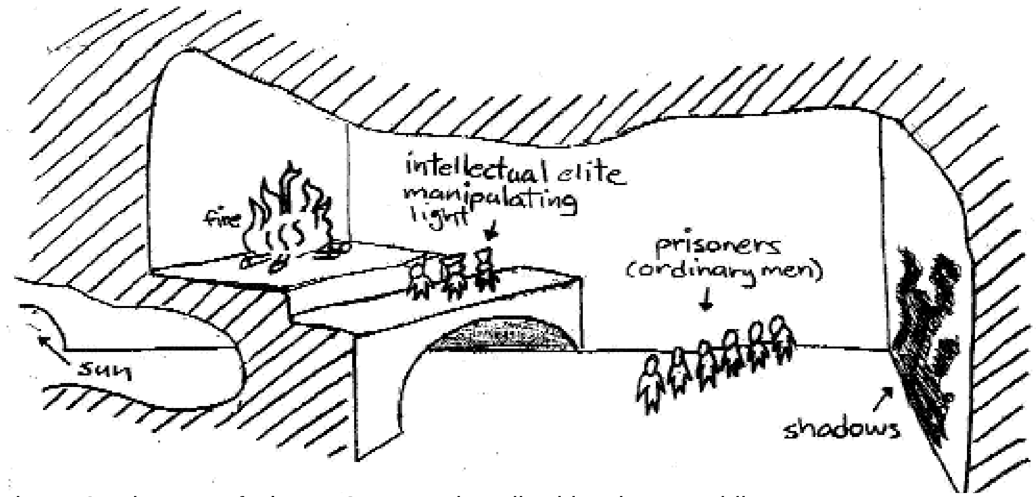


Figure 2: Diagram of Plato's Cave as described in *The Republic*.

In light of Plato's myth, it is strangely ironic that the scientists at UIUC, creators of arguably the most advanced virtual reality system, also known as the CAVE, accomplished their task by devising a system that deprives people of their proper senses, and projects a false (virtual)reality on the walls of an enclosed chamber. (The CAVE will be discussed in greater detail later).

3.2 Renaissance

In general terms, interactive art usually entails engaging the observer, or user who, responding to sensory and or intellectual stimuli, activates some part of their body to invoke a transformation within the present installation. Thus the person engages in a "dialogue" both mentally and physically. We must observe however, that this dialogue is analogous to that established with the viewer in static art works such as painting or sculpture. On this subject graphic designer and animator Saul Bass states the following:

> *When a painting surface has objects placed upon it, a sequence of time must be assigned to these objects. We see them sequentially, albeit with infinitesimal time duration between each step. The eye we are told, has the capacity to absorb in one Gestalt an average of four or five objects. When the points of perception in a painting are increased to ten, twenty or thirty it becomes necessary to organize these points of perception into a rhythmic sequence which enables them to be seen in a larger, simpler relationship and still allow each to express itself individually. These great sweeping rhythms and patterns, formed of many diverse elements, course in and out of the painting space; as a result, the viewer, upon entering the painting, has motion and time experience.*[2]

2 Bass, Saul, *Movement, Film, Communication*; in *Sign, Symbol, Image,* ed. Gyorgy Kepes, George Braziller, New York, 1966, p200.

To elaborate on this we invoke an example in which Plato himself makes an appearance; the remarkable Renaissance mural by Raphael known as "The School of Athens".

Figure 3: Raphael, *School of Athens*, 1509-1511.

In it we find a masterfully rendered perspective space of huge proportions, populated by a cast of characters that simultaneously represent classical and contemporary icons. The seated Heraclitus in the foreground is generally considered to be a portrait of Michaelangelo; Euclid in the middle of the group at the front right could also be Bramante. At the very center we find Plato and Aristole, apparently extolling the virtues of the opposing philosophical standpoints of the Renaissance; metaphysical vs. the natural. The rest of the cast are divided centrally along similar philosophical lines.

In a spectacular fashion, Raphael resolves a highly sophisticated perspective configuration and a philosophical configuration simultaneously. The philosophical viewpoints of the various figures are meant to be known to the viewer. They are meticulously placed throughout the work to be interpreted sequentially through a path dictated by elaborate spatial and architectural organization; as if the viewer was acting as the jury in a grand debate.

As described by Saul Bass, it prompts viewers to embark in a passage through time and space as viewers decide how they identify with each character and to establish the extent to which they accept the philosophical viewpoints they represent. The viewers interact with the painting by taking on a role of interrogator amongst the extensive cast of characters in an exercise that ultimately articulates their own philosophical values. The grandiose stage set by Raphael is a model of interactivity in painting, and the debate that it projects serves as a precursor to one between art and science that would take place centuries later.

Figure 4: Leonardo da Vinci, *Embryo in the Womb*, 1510.

The fusion of art and science is observed in a more literal sense in some of the work by Raphael's contemporary, Leonardo da Vinci. His anatomical drawings such as "Embryo in the Womb" were without question the most accurate that had ever been made at that time. So accurate in fact that they could conceivably be used as scientific documents to this day despite some minor misrepresentations. Yet, we simultaneously appreciate these illustrations as works of art in every sense. Through the massive diversification of science through the following centuries, and through the streaming and specialization of all aspects of culture, a dichotomy is perceived between the arts and the sciences. Yet we will observe example after example demonstrating that the mode of operation illustrated by Leonardo has persisted to this day.

In Leonardo's anatomical diagrams we observe the notion of "data representation". Besides its powerful aesthetic, the work has a quantitative aspect in relaying a specific set of information. Thus we can say that the work has direct communicative quality. In the late 20th century maintaining this quality will become an enormous challenge as storehouses of non-tangible information reach astronomical dimensions; a challenge that will encompass the function of the interaction artist. The Theodore Gericault masterpiece "Raft of the Medusa" provides the opportunity to examine the origins of the communicative role of contemporary art.

Figure 5: Theodore Gericault, *Raft of the Medusa*, 1818-1819.

In the centuries that preceded technological reproduction of visual material on a massive scale, the role of painting and sculpture as a communicative medium cannot be underestimated. This large painting tells the story of maritime disaster involving a ship that was lost, through incompetence, off the coast of Africa. Some of the Algerian immigrants on board managed to survive to relay this horrific tale to the citizens of France who responded in shock, inspiring Gericault to create this work through a course of painstaking research and detail. The artist went so far as to interview the survivors to create an image of the utmost accuracy.

Although the resulting work portrays events in a somewhat romanticized configuration, it is without a doubt the most vivid representation of this tragic episode. The painting created a sensation in its time; people travelled from far and wide to view it as it embodied the definitive image of events that had captured the attention of the population. It is important to recognize the unique communicative ability embodied in this work; to this day this artifact continues to be the primary witness to an incident from two centuries ago. Again, it is a form of constructed data representation where the unique positioning of the medium of painting at that point in history communicated a set of visual information that had no other outlet. The contemporary creation of interactive installations inevitably entails a reconfiguration of instruments designed with specific communications functions; systems which record, transform and redisplay images. The task of the interactive artist today, not unlike Gericault, is to configure these in such a way as to find the language that is unique to them.

3.3 Motion and Modernity

In many of the examples given so far the relation to interactive art can seem tenuous because they are for the most part completely static; no parts move, and no aspects of the physical piece change during the period of viewing, creating a dialogue which takes place within the viewer’s own intellect, or that of others present. As the machinery of the industrial revolution found its way into all aspects of life, the face of art changed as well. The dynamic configurations which are a central component of interactive art found their way into the mainstream art world in the first part of the 20th century. It is interesting to observe how this was anticipated in conventional art works, painting, sculpture and photography around that time.

In this vein, the work of Eadweard Muybridge cannot be overlooked. Through the development of a sophisticated array of cameras and electro-mechanical shutter mechanisms, Muybridge created an exhaustive collection, of time-lapsed sequences of imagery of humans and animals engaged in a endless variety of kinesthetic activities. As obvious as it may seem that an image of something in motion should suggest that motion, the placement of the consecutive images in sequence creates a sensational and unexpectedly powerful impression of that. These sequences in fact revealed aspects of bodies in motion that were inaccessible to the naked eye; it was a bet over whether or not all of a horses legs come off the ground when in full gallop that prompted Muybridge to undertake this method of photography (they do).

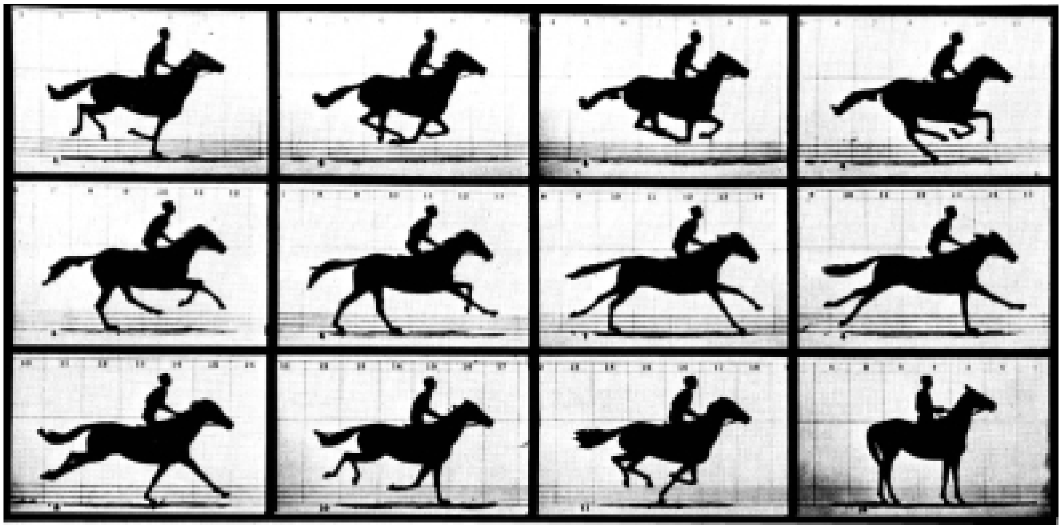


Figure 6: Eadweard Muybridge, *The Horse in Motion*, 1878.

The widely publicized collection of this exhaustive body of work, called Animal Locomotion continues to fascinate. In 1880, Muybridge created a device he called the zoopraxiscope where the galloping horse sequence of images were placed on the inner surface of a slotted, spinning cylinder. The view through slots created a fully animated image of a galloping horse, and thus cinema was born(a subject that will not be ventured into for the purpose of this thesis.) It is notable that notwithstanding the overwhelmingly scientific flavor of the artifacts created by Muybridge, we cherish at them equally, as we do with Leonardo's masterful anatomy drawings, as art.

The influence of Muybridge's work in the world of art is considerable. American painter Thomas Eakins collaborated extensively with Muybridge; using his motion images to apply correct posturing of figures and positioning of limbs in his realist paintings.

Figure 8: Thomas Eakins, *A May Morning in the Park* 1879-1880.

The Futurist obsession with speed generated works with features bearing direct similarity to the photography of Muybridge and his contemporary Georges Etienne Maray, who's work differed marginally from the former in that he generally displayed movement through multiple exposures in a single image. The influence this had on works such as Umberto Boccione's *The City Rises* is unmistakable. Further influenced by modern technology, a theme of mechanization also surfaced, complementing the theme of locomotion. The influence on Cubism is observed in the compositions of Georges Braque where multiple views over time compressed into a singular image.The use of mechanization to suggest movement in still paintings was examined to great lengths during the Cubist, Futurist, and Dada movements, as is observed in works such as "Child Carburetor" by Picabia, and "element mecanique " by Fernand Leger.

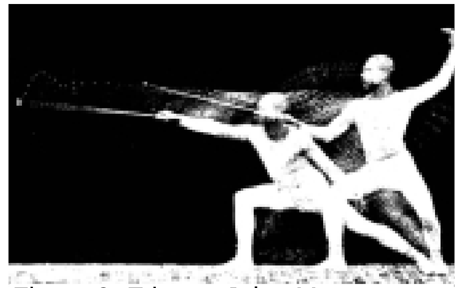


Figure 9: Etienne Jules Maray, *Measuring the Speed of a Swordthrust by Means of Photochronography*, 1890.

Figure 10: Umberto Boccione, *The City Rises*, 1910.

Figure 11: Fernand Léger, *Mechanical Element*, 1924.

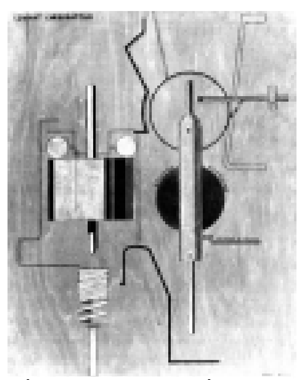
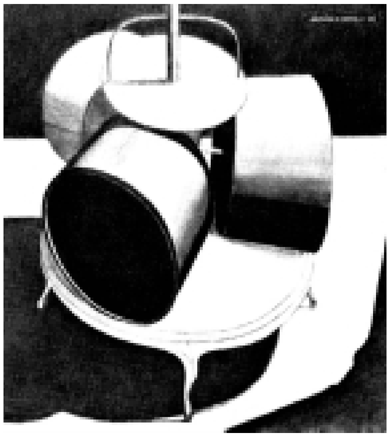


Figure 12: Francis Picabia, *Child Carburetor,* 1919.

Figure 13: Georges Braque, *Violin and Palette* 1909-1910.



In the work of Marcel Duchamp we see both the use of multiple exposures, as in *Nude Descending the Staircase*, and mechanization as in his masterpiece *Large Glass*(1915-1923), of which similar aspects can be observed in *Chocolate Grinder* (1913).

Figure 14: Marcel Duchamp, *Chocolate Grinder* no.1, 1913.

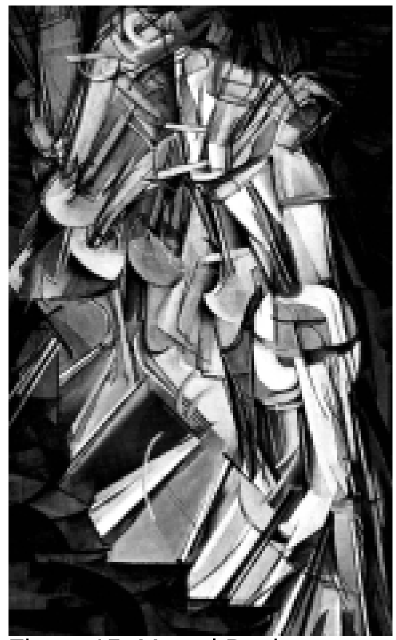


Figure 15: Marcel Duchamp, *Nude Descending a Staircase #2*, 1912.

Duchamp however, more than any of his contemporaries, would become a highly conspicuous player in 20th century art. He quickly abandoned painting and undertook a life-long body of work that challenged the very nature and role of art in society; and in each new enterprise new avenues of expression would be exposed, thus his stature as one of the century's most influential artists continues to grow.

Figure 16: Marcel Duchamp, *Bicycle Wheel*, 1951 (third version; original 1913).

Early in his career he introduced the concept of the *Readymade*; common manufactured objects, slightly modified or not, placed in an art gallery context, prompting viewers to challenge the legitimacy of the object as art. One of these early works, *Bicycle Wheel* (1913), consisting of a bicycle fork and wheel installed upside down on a stool, is of particular significance because it introduces both the attributes of movement and of physical interaction with the viewer by spinning the wheel, making it one the first examples of kinetic art and of interactive art.

Duchamp's discourse in challenging the nature and public perception of art is pivotal as this challenge was taken up in every imaginable form over the decades that would follow; taking on a new significance with every art movement that would follow.

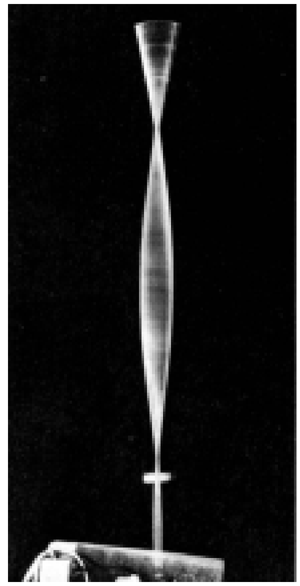


Figure 17: Naum Gabo, *Standing Wave*, 1920.

The first fully kinetic work of art is generally considered to be the "Kinetic Sculpture"(1920) by Naum Gabo; a rapidly vibrating, vertical steel rod activated by electro magnets. Around that time, Alexander Calder made his appearance on the now established kinetic art scene with his "mobiles" and "stabiles", some motorized, others subject to passing atmospheric conditions. These works are successful in a dual capacity as they satisfy the viewer's appetite for form while simultaneously exhibiting and demystifying basic properties of physics; again the artist-scientist dichotomy resurfaces.

Figure 18: Alexander Calder, *Aluminum Leaves*, 1940.

The central figure in the emergence of technological art is without question the Hungarian Laszlo Moholy-Nagy. The true embodiment of the artist-scientist, Moholy-Nagy made no distinction between visual media produced for artistic purposes and that made for practical purposes. Where renaissance artists used their talent to reveal the divine structure of nature as designed in God's image, Moholy-Nagy worked similarly and used all means possible of rendering shape and imagery to expose the sublime, purity of form. In his view, all means available were acceptable in attaining these ideal forms. The brush or the camera were but intermediary elements. In this mode, he produced a vast and varied body of work which, through a wide disregard for conventional artistic method, would introduce important new concepts, materials and techniques in artistic practice. Perhaps the most relevant of these was in the use of light which he predicted would precipitate an entirely new form of art. A prediction that he would later abandon, but would ironically be realized after his time had passed. His most famous work done in anticipation of this is known as *Light Space Modulator* (formally named *Light Prop for an Electric Stage*).

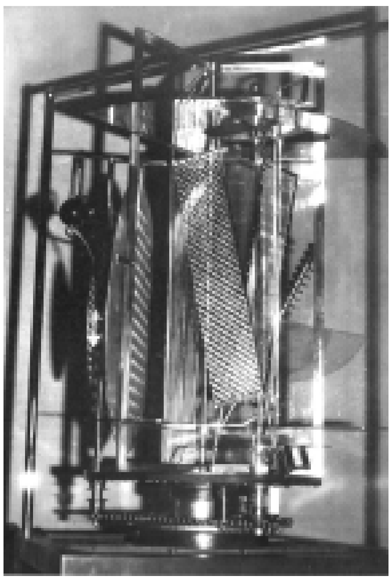


Figure 19: Laszlo Moholy-Nagy, *Light-Space Modulator*(Light Prop for an Electric Stage), 1930.

This sculpture consists of various metallic rods and panels in a mostly vertical configuration, attached to a series of gears and motors which rotated the hardware slowly to the humming of its mechanisms. Around it were a series of colored lights which were timed to ignite on cyclical intervals, casting light upon the viewer, and creating an ever-changing series of shadows on the surroundings. This marks the first prominently successful use of electric light in the creation of sculpture. Although it is essentially a sculpture, the piece could not be appreciated strictly as a self-contained object since its light sources made use of the surrounding environment to work their effect.

What we observe is the precursor to the large number of subsequent installations that create environments through the manipulation of light which Moholy-Nagy unfortunately never lived to see. These works would use neon, lasers, holograms, projected imagery and ultimately interactive computer graphics.

3.4 Post-War Technological Fusion

And so the stage has been set for the contemporary practice of the technology-based art installation. Events in Europe and the subsequent war would have a profound impact on the demography of artists throughout the world. With the massive immigration of European artists and scientists to America, so moved the focus of the Western art world from Paris to New York. The reshuffling of a large number of prominent artists, combined with the introduction of a plethora of new technologies as a direct result of the war effort set the stage for unprecedented diversification in the practice of art. In the decade that followed the war, attention was drawn towards the abstract expressionism movement surrounding the New York school. At the same time the genesis for a highly technological art trend was under way. Among the early contributors was Gyorgy Kepes who came to the United States by invitation of his countryman Moholy-Nagy to help found the "new Bauhaus" in Chicago.

Although the initiative was quickly abandoned, Kepes succeeded in raising important issues in relation to the art world. By the mid-fifties, the art world was still very much preoccupied with the inward search for the sublime as manifested by the abstract expressionism movement. Kepes recalled themes raised earlier by Leonardo and much later Moholy-Nagy, that technology has the ability of revealing aspects of nature which are normally in accessible to the human eye.

Figure 20 : Electron micro-graph: bismuth telluride sample from *Sign, Symbol, Image*, Gyorgy Kepes.

Through a series of gallery exhibitions and books, most notably "The New Landscape", he postulated that previously unattainable visual material made accessible through technology, whether it would be high-altitude aviation, or high-powered microscopes was not simply viable material for artist purposes, but that it was vital and essential to the practice of art and that it was a fallacy for humankind to ignore its environment in the pursuit of art. Kepes would later form the Center for Advanced Visual Studies at MIT, which over the late 60's and throughout the 70's became a beacon for tight collaboration between technology and art.

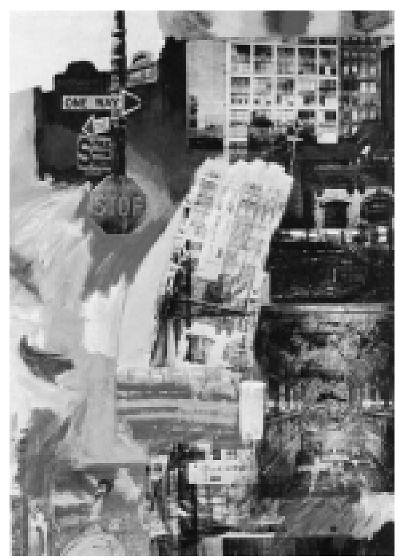


Figure 21: Robert Rauschenberg, *Estate*, 1963.

While Kepes was formulating his manifesto on the role of the environment in art, a very important artist emerged postulating similar ideas, and transformed the art in a manner that would eclipse all of his contemporaries. For Robert Rauschenberg, the environment was mass media; not only his source of inspiration, but an bottomless source of material for art.

In the spirit of Duchamp, Rauschenberg accepted all objects as valid artistic material and proceeded to create an extensive body of painting and sculpture by combining, reorganizing, modifying or painting these objects with a highly tuned sense of composition, pulling the art world out of the densely introspective mood that had prevailed since the war and setting the stage for the Pop Art movement. Rauschenberg's activities extended far beyond creating art objects. His well established collaboration with composer John Cage, and choreographer Merce Cunningham produced a series of avant-garde theatre productions exhibiting notions of free form, spontaneity and audience participation.

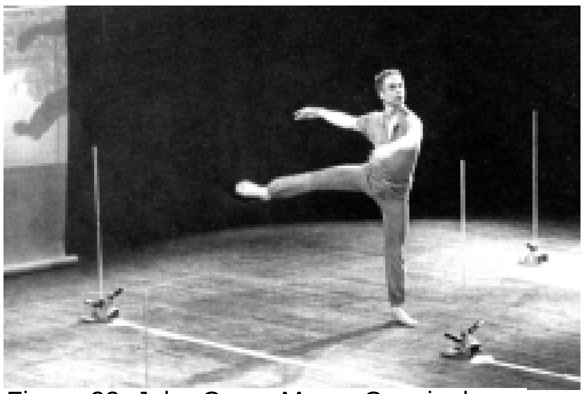


Figure 22: John Cage, Merce Cunningham, Billy Kluver, *Variations V*, 1965.

What is less commonly noted about the career of Robert Rauschenberg is his role in merging art and technology. His association with Swedish engineer Bill Kluver was an extremely prosperous one and remains a model of collaboration.

A Bell Laboratory employee, having spent several years assisting numerous other contemporary artists with the engineering of their works, Kluver's collaboration with Rauschenberg led to the creation of E.A.T; Experiments in Art and Technology. The result of this enterprise yielded several hundred works using all available technology. If nothing else, it accelerated the passage of emerging technology from the research lab to the art gallery. It was a potent enterprise about which art historian Douglas Davis states:

Figure 23: Robert Rauschenberg, Billy Kluver *Oracle*, 1965.

"The object of collaboration between artist and engineer, Kluver pointed out, is a work that neither could have produced alone".[3]

3 Davis, Douglas, *Art and the Future*, Praeger Publishers, New York, 1973, p. 71.

This statement acknowledges the impact of diversification and specialization of task have had on our culture. It also identifies the absence and anticipates the arrival of a different breed of technically competent artist who embodying all of those skills, will execute works with technological sophistication while carrying the artist's singular vision.

As artists and engineers collaborated prosperously using lasers, motors, synthesizers and video, important developments were taking place in computer research; particularly the invention of real time interactive graphical computer display systems. In the late sixties Ivan Sutherland and Charles Csuri, working under a National Science Foundation Grant, developed programs that created moving graphical images on a computer monitor which could be manipulated with a light pen. On this subject he stated at the time

I can draw on the display tube, and move my drawing around the moment I create it, in real time. I can turn any form over and around, watching countless options, instantly. The moment of creation and editing become one.[4]

Figure 24: Charles Csuri with light pen, 1968.

This seminal moment denotes the first ability for instant interaction between two distinct realms, physical and virtual, the truly unique and powerful quality of computer interaction. In this we see Moholy-Nagy's abandoned dream reawakened; an art form that is dynamic, plastic, completely controllable, and consisting solely of light. It would take nearly two decades before this technology would be commonly available with the appearance of the Apple Macintosh in 1984.

It was quickly observed that for all its brilliant potential, the confinement of this plastic light to a cathode ray tube could create somewhat of a distancing barrier and could be somewhat unsatisfactory. Sutherland wasted little time in addressing this by creating the first head-mounted augmented reality system in 1970.

4 Davis, Douglas, *Art and the Future*, Praeger Publishers, New York, 1973, p. 102.

As illustrated, Sutherland is wearing a headset that projects separate stereo images in each eye by reflecting them off glass plates thus maintaining his ability to see the physical space. The stereoscopic effect gives the impression that the projected image is suspended in space within the actual, physical room. The apparatus mounted atop his head tracks movement and adjusts the image accordingly thus anchoring the virtual image in physical space. The striking visual illusion created by this device has barely diminished to this day. This technology soon found its niche in military and aeronautical applications and succeeded decades later to find its way into the mainstream through practical industrial application.

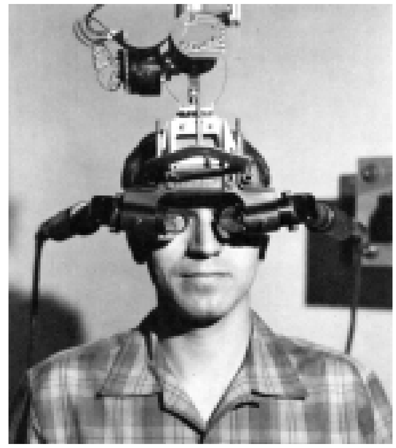


Figure 25: Ivan Sutherland wearing a head-mounted computer display system, 1970.

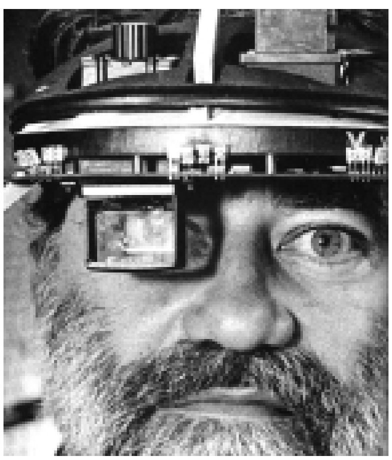


Figure 26: Boeing assembly worker, 1997.

Such is the case at Boeing Aircraft of Seattle where enhanced reality systems are used to reduce error in the assembly of massively complex wiring systems.

Whereas it may be acceptable to wear bulky headgear on the job, for many, this is an intrusive and unacceptable method of creating immersive interactive environments. Head mounted apparatus can have an undesirable disorienting impact, and have the unfortunate effect of restricting users' normal use of their senses and of their physical mobility. Furthermore, the exercise of putting on and adjusting the gear creates and additional access barrier. Alternatives were sought by artists and researchers alike.

3.5 Contemporary Practice

Figure 27: Myron Krueger, *Video Place*, 1989.

The alternate approach for creating a responsive environment was taken by the pioneering interactive artist Myron Krueger. Starting in the early seventies, Krueger used a configuration where the user would interact with video images projected onto a large screen. Cameras would read and interpret the movements of users and use them as input to the graphical program on the screen. At a time where computers were large, expensive and relatively slow, Krueger peerlessly devised and programmed his own hardware to create installations that set such high standards for interactivity that they remain benchmarks to this day. His experiments of the seventies and eighties are still difficult to reproduce on the most recent computers. His endeavor demonstrates a remarkable fusion of artistic and scientific talent a subject on which he is quoted early in his career:

These steps towards a collaboration between art and technology represent a positive trend. An artist who is alienated from technology cannot speak for a technological culture, any more than a technologist who disdains aesthetics can design a humane technology.[5]

Thus by focusing on the computer's unique ability to respond in real-time, Krueger becomes the anticipated 20th century renaissance man, devoutly and completely in charge of all technological and all artistic aspects of his creations.

It would come as no surprise that the artist value of Krueger's work has been challenged. His work has been criticized for being excessively focused on technological wizardry and shallow in content. But if one considers that the configurations he invented have evolved into standards in contemporary interactive art, and that he created them with artistic intent, his stature as an artist is difficult to challenge. His early works will unquestionably stand as landmarks in the developmental stages of interactive art and as footnote in the enduring dichotomy of art and science.

5 Krueger, Myron, *Artificial Reality*, Addison-Wesley, Reading, 1983, p.10.

As counterpoint, it is worthwhile discussing the work of video artist Bill Viola. Beginning the early 1970's, Bill Viola has generated a vast impressive body of highly technological work focused mainly around video. Although Viola's work for the most part is dynamic but not interactive, it stands in contrast to Krueger's in that it has never suffered from being overwhelmed by its own technological makeup. His works *He Weeps for You* and *Heaven and Earth* serve as examples.

For *He Weeps for You,* Viola installs a copper pipe coming down from the ceiling with a valve at the end which is open just enough to allow a drop to form slowly. Directly beside the forming drop is a video camera which is using the optics of the drop to convey a wide-angle projection of the room, and those within it, on the wall behind the pipe. Gradually, as the drop grows, the projected image grows with it until the drop breaks free, landing on an amplified drum below creating a huge resonant sound in the room. The cycle then repeats itself.

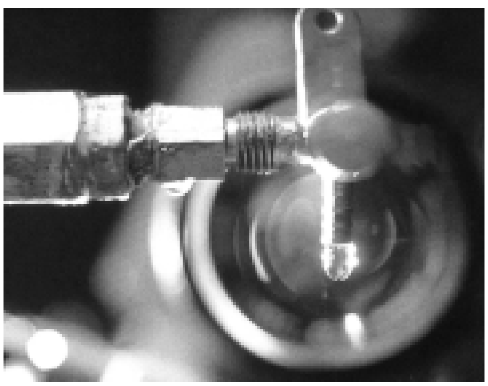


Figure 28: Bill Viola, *He Weeps for You*, 1976.

In *Heaven and Earth*, two black and white monitors are placed face-to-face in a vertical configuration at eye level. The lower screen shows images of a newborn baby; the upper shows images of an elderly person on the verge of death. The screens are placed in close proximity such that the reflection of one can be seen on the other.

The remarkable quality of Bill Viola's art is that though the works have a heavy technological makeup, the conceptual content always dominates. Viola displays a remarkable talent for using and transforming highly technical components with same ease that a painter manipulates pigment. The componentry is molded masterfully to convey the conceptual motives of the artist in an effortless and unconvoluted manner; a quality that unfortunately eludes many technological artists.

Figure 29: Bill Viola, *Heaven and Earth*, 1992.

The final work observed in this long chain of interactivity is one by interactive video artist Jim Campbell. Jim Campbell effectively bridges the gap between Myron Krueger and Bill Viola as he is a video hardware engineer who has applied his professional skills to produce a series of works that make use of the computer's unique ability to react instantaneously, while applying a sensitivity to content that is reminiscent of Viola. His work has an affinity to Viola's by presenting diverse elements in such a way that an intimate and immediate intellectual exchange can take place without being convoluted by the technology involved. Like Viola, he has the rare ability to present a technically complex work where the technological texture never overwhelms the content of the piece.

Figure 30: Jim Campbell, *Digital Watch,* 1991.

In *Digital Watch*, the viewer is presented with a large video image of a watch superimposed on two other video images. The image outside the watch is the a live video image of activities taking place directly in front of the screen; the image inside the watch shows still images of activities in front of the screen 5 seconds in the past. Each time the second hand moves one tick, the still image updates. The images are taken from separate cameras, showing the viewer at different angles.

The configuration of this piece is clever, yet simple enough that the viewer will not dwell on its technological makeup. What comes through first and foremost is the temporal distortion that he creates instantaneously. The forced delay of the second still image traps the viewer into a temporal void during which their focus will oscillate between the two images as they count time on the big watch. Numerous relations can be drawn with other artistic periods; it could be interpreted as literal enactment of the values of Cubism. Multiple views of the subject, disparate spatially and temporally, are juxtaposed in a single composition, furthering the notion that the work of such artists fits into a wider context that that of a technologically relegated domain.

3.6 A Framework for the Present

In presenting a historical view of interactivity, the division of task between the artist and scientist appears less entrenched. Technology developed through science has continuously and irreversibly changed the world we live in, but as our art production has always served to examine and interpret our surroundings and perceptions, technology has always played an integral role in its creation. From this broad perspective, the situation where art exists distinct from the realm of science seems like the exception. In this century, shaped by task specialization resulting from the Enlightenment and the Industrial Revolution this exception has appeared to be the norm. This norm is brought into question by Kinetic artists is demonstrated in Jack Burnham's commentary on the shortcomings of this art movement:

...the relative aesthetic of Kinetic Art is significant in itself since the desire to make art kinetic is one of the prime artistic urges of the present century; to misinterpret this is to reject the direction to which Western Art has committed itself. The technician has consistently failed to make machinery conform to the aesthetic precepts of our culture; instead, it has been the artist who was forced to try to make his art relevant to the prevailing technology. The Kinetic artist, along with his enemies, has often sensed that he has united his art with forces inherently at odds with artistic endeavor. Even the engineer with his superior training has so far not produced superior Kinetic Art, usually the opposite. Successful Kinetic Art until now has either defied or trivialized the principles of mechanical invention.[6]

Decades later, the proliferation of computer technology has created the setting for an individual who's role would be difficultly pinned down as artist or technician. These are the materials of the contemporary artist, and their technologically demanding mastery has revived the function of the artist-scientist. Thus, a framework for artistic practice is established; it is within this framework that works in the following sections are presented.

6 Burnham, Jack, *Beyond Modern Sculpture*, George Braziller Inc, New York,1967, p.

4 Experiments and Works

This section comprises a detailed description of work produced for this thesis grouped in two main categories. The first, *Immersive Interactive Environments*, contains work where subjects interact by moving their whole bodies over surfaces or areas. They are referred to as *immersive* because the interaction zone overwhelms the size of the subjects taking advantage of their senses, both directly and peripherally so they may feel immersed inside the driving application.

In the second part, prototypes involving physical models are presented. The experiments presented here are an attempt to break free from the confines of the two dimensional images that are the standard means of interaction with computational media. In this section are described I/O designed to reshape or redefine the standard parameters of interaction.

4.1 Immersive Interactive Environments

4.1.1 *metaField*

The metaField is a 12ft by 16ft interactive floor. It works by identifying the position of users with the use of a video camera placed high above the floor, and by projecting video images on the floor, also from high above, that change according the the movements of the users below. It is a generic configuration suitable for a wide variety of applications.

4.1.1.1 Background

Floor-based installations are not a new concept; in particular, one simply needs to examine the Carl Andre work *64 Pieces of Magnesium*. Andre's work is notable in way that it challenges the pervasive verticality of sculpture that has dominated the practice since antiquity. Although this work has no moving parts is it different from other static works of sculpture in that it invites you to walk on it; establishing it's first primary of interaction. Consisting of 64 identical magnesium plates in a square configuration, this work is minimalist in that its complete physical configuration is consumed almost instantly. Within moments of seeing it is completely revealed to the viewer; it holds no surprises, no aspects of are unknown. In the tradition of minimalism, the temporal experience of the viewer

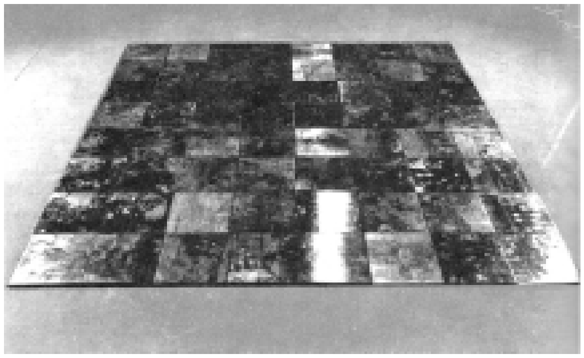


Figure 31: Carl Andre, *64 Pieces of Magnesium*, 1969.

walking over the work becomes central. Having no moving parts, this fundamentally interactive work defines the space within which future mechanized and computerized works will exist.

The work of James Seawright “Network III” is a predominant example of early dynamic floor spaces. Pressure sensitive devices are placed under a carpet. When the subject walks over them they trigger patterns of ceiling lights.

Figure 32: James Seawright, *Network III*, 1970.

Here the notion of verticality is reintroduced by prompting the subject to make direct associations between floor and ceiling. Although this particular configuration could lead to neck pain, it exhibits other interesting properties. One is that, like Andre’s work, it has a very low threshold of interaction; one has only to walk onto it. This was an important consideration in the creation of the metaField.

More recently and more locally, the Interactive Cinema group at the Media Lab created an interactive floor installation called Cinemat. Here, a pressure sensitive floor mat is used similarly to Seawright, but in conjunction with a adjacent vertical video projection screen. The direction and speed of the subject's actions on the sensor mat are used to create a narrative of pre-taped video clips. The coupling of a vertical projection screen with a reactive floor is evidently a potent configuration for interactive installations.

4.1.1.2 Objective

The metaField came about from the desire to create an interactive environment with the following qualities:

- the ability to accommodate one or several users
- the possibility of full-body, kinetic interaction
- the potential for collaborative, mentally challenging, artistic, and/or practical applications
- low threshold for engagement

4.1.1.3 Configuration

A floor-based configuration seemed to have the best ability to accommodate the criteria and so a system involving a video camera and projector pointing down was devised. The projector and camera are placed high enough such that their field of vision or projection can cover the full surface of the floor. A floor size of 16ft by12ft was deemed suitable as it supercedes the human dimension sufficiently to allow the subject a great degree of mobility, while it remains small enough maintain an acceptable level of granularity and brightness in the projected image for viewing from eye height of the average person.

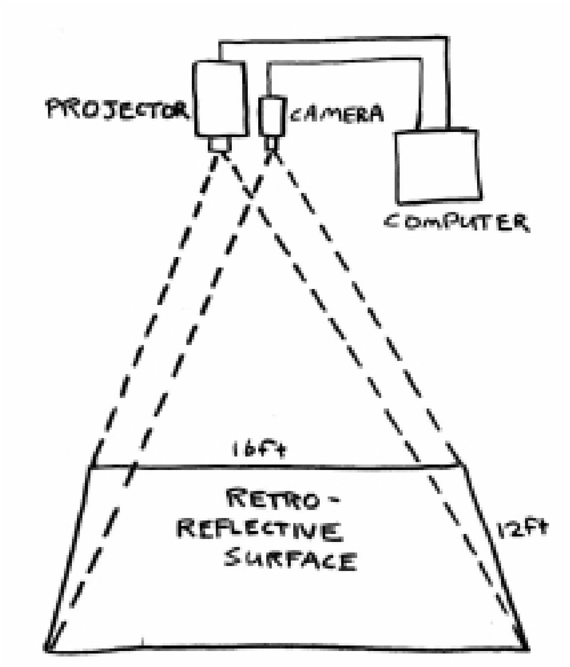


Figure 33: metaField system configuration.

The construction of physical configuration of the metaField was undertaken by the author with assistance from fellow research assistant Tim McNerney. The original floor consists of twelve 4'x4' masonite panels, painted white and then smothered in microscopic glass beads while the paint was still wet. This surface provided the retro-reflective quality that would create desirable high-contrast images in the vision of the video camera. The projector used for this application was a prototype Texas Instruments micro-mirror device; the video camera used was a portable DV unit. Both the devices were suspended 25ft above the floor surface. This original configuration was installed in the *Cube* in the Media Lab. Subsequent installations used different camera/projector configurations as well as different floor surfaces. *Scotchlite* material was found to create adequate contrast with greater durability and washability.

In all configurations, SGI computers were used. All software was written in C++ using the Inventor tool kit for the 3-D graphical elements. Several people were involved in creating the various metaField software applications. Specific authorship is indicated with the description of these components.

4.1.1.4 Software

The software driving the system has two distinct components. One accepts the incoming video stream and draws basic information from it. The second takes this information and uses it to control the display component.

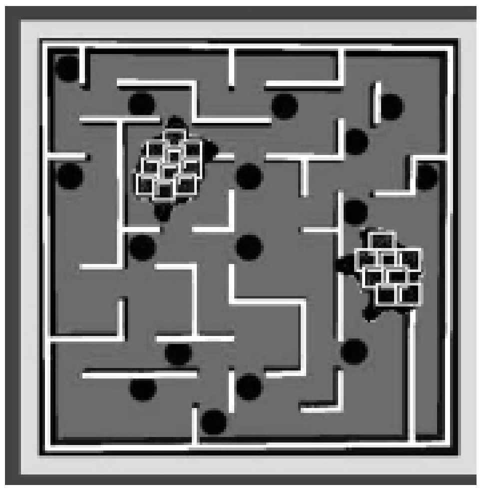


Figure 34: Looking down from above, this is what the *glimpser* sees. The maze in the background is the projected application. The white squares denote two people that have been identified by the glimpser.

The software component which accepts the incoming video stream is a generic vision program written by John Underkoffler of the Media Lab, known as *glimpser.* This program, written in C++ on SGI computers, has the ability to find regions of a specified size and specified color from incoming video frames. It is a server program that awaits requests over a standard network. Thus the display or application component of this system runs completely independently of the *glimpse*r and is invoked separately.

The application component begins by telling the *glimpser* the sort of image data it requires. In the 16ft by 12ft configuration described above, it would be required to find regions of black that would correspond to 4 inch squares at floor level. This granularity is chosen to allow for the recognition of the limbs of the subject while not being so fine as to slow the performance of the *glimpser*. Once the glimpser is calibrated to specifications of the application, a steady flow of data takes place, consisting of an array of points where the requested black regions were found.

What happens to this data once the application has it in its possession depends very much on the nature of the application. In cases where it is necessary to differentiate between people standing on the floor, a clustering algorithm is used to determine which regions of black are associated with which person. Naturally, if standing very close together, confusion will arise; but as demonstrated in some of the following applications, this may have an interesting and desirable effect. All of the applications detailed here work with the metaField as described above.

4.1.1.5 Applications

Dances with Words

Dances with Words is an application where collaboration between users is the main objective. When the game is at rest, orbs with words revolving around them hover at the perimeter of the floor. When a person walks onto the floor, one of the orbs immediately finds the person and follows them wherever they go on the floor with the words continuing to circle around them. The orbs change size depending on the gestures of the person. If the person stretches their arms out wide, the orb will become large, if they hold their arms close to their body their orb become small. When two people approach each other a tension arises between their orbs. When they get to close, their orbs merge with a frenetic man-

Figure 35: Dances with Words.

ifestation as if one orb is attempting to dominate the other. When the two people separate they may have exchanged orbs.

Aside from its playful aspect, the orbs and the tension that occurs when two of them get close together is an interesting metaphor for the personal space we maintain around our bodies at all times. Interestingly, adults using this application would immediately abandon their personal space in favor of the orbs, inducing unexpected social behavior between strangers and friends alike. On other occasions, groups of children were allowed to take part, usually resulting in an uncontrollable frenzy of activity.

The development of the Dances with Words software was a highly collaborative exercise involving the participation of undergraduate Ed Holtzwar, and Media Lab research assistants Tim McNerney and Tara Rosenberger as well as the author. This application required a clustering algorithm which served to distinguish people from each other on the metaField surface. This algorithm software was implemented by Tim McNerney.

Letter Blocks

The *Letter Blocks* application begins with a large array of white three-dimensional letter blocks projected on the floor, each with one side visible with a letter on it. When a person steps onto the floor the blocks, which are about 8 inches wide rotate on themselves revealing the next letter of the alphabet on the next side that appears. As the letters turn they assume color; each person walking on it will

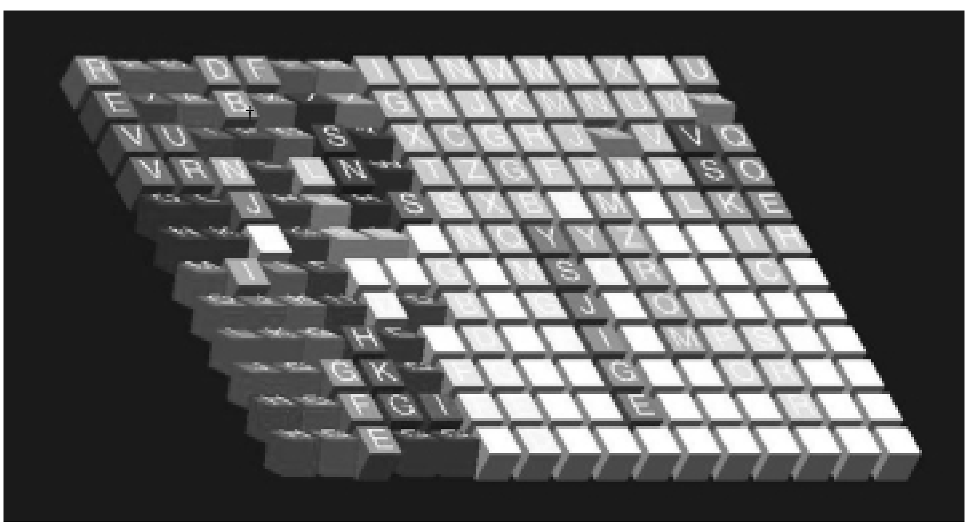


Figure 36: Letter Blocks - angled view of 3D model projected onto floor.

assume a different color. People attempt to create words by moving around or attempt to convert as much territory as possible to their color. When a given area is inactive, it slowly fades back to white.

The creation of the *Letter Blocks* application came somewhat in response to the previous Dances with Words. It was an attempt to address the unsettling, fleeting quality of the orbs. The lack of stable elements on the floor surface had a delaminating effect on the graphics; an unconvincing sensation that the orbs were part of the floor. With Carl Andre's magnesium squares in mind, a more architectural approach was taken. The blocks would be at fixed positions with respect to the existing real architecture, and they would never all be moving simultaneously. The fade back to white after a a short period of inactivity is intended as an inference that the surrounding architecture is pulling it back to its inert state. This strategy was effective in anchoring the projected images to the floor and diminishing the undesirable "painted projection" effect; thus effectively demonstrating that the content of projected images has a considerable impact on their perceived concreteness. The *Letter Blocks* application also introduced the notion of creating a deeper sense of immersion by preoccupying the subject with an explicit intellectual exercise. These two key aspects seemed to work in cohesion to create a more engaging experience.

The Letter Blocks software was written the author.

Data WalkAround

The *Data WalkAround* application explores the possibility of using a large floor display system to study data models. A given data set is selected and rendered in to a three-dimensional model. This model is projected onto the floor of the metaField. When a person walks onto the floor, the model reorients itself so as to be seen in the correct perspective from where that person is standing. When the person walks around the model, the perspective view changes simultaneously such that the three-dimensional object is always seen in correct perspective, regardless of the position of viewer.

Although this application was not thoroughly successful, it was insightful. The immediate disadvantage to this strategy is that only one person can view the model correctly at a time. This may be fine for more secluded or more personal viewing environments, but works in direct contrast to the inviting omni-accessibility that is one of the floor interface's great assets. This application also raised other issues about the feasibility of projecting three-dimensional objects. In previous models, the third dimension had only been used marginally. This applica-

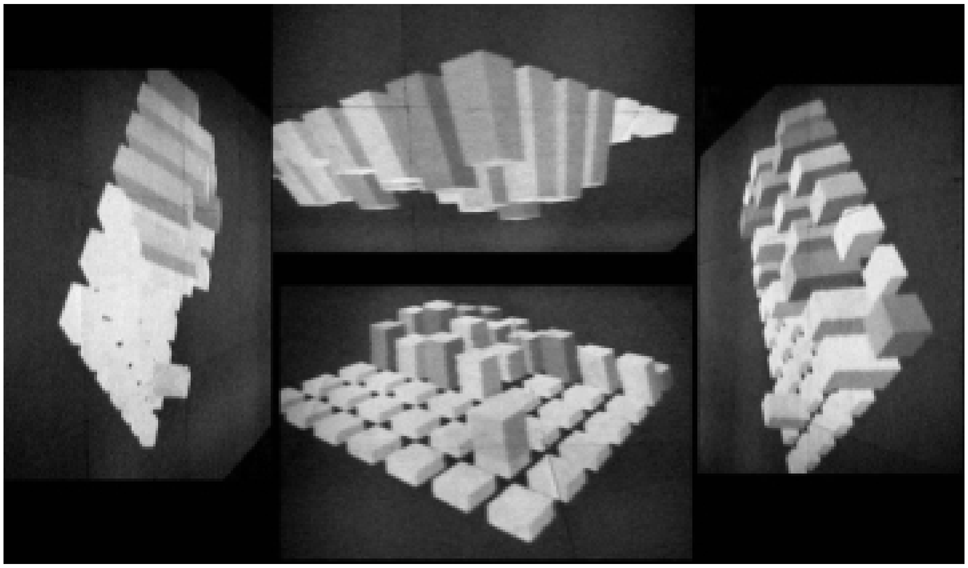


Figure 37: Data Walkaround - The data model projected onto floor is show from four different angles in this composite image.

tion revealed that full blown three-dimensional object requires a head on view to be effective. The low angle views of viewers on an floor-based projection quickly distort and diminish the intended three-dimensional effect.

The Data WalkAround application was written by MIT undergraduate Matt Lee with assistance from the author.

Puzzle

In this application, the traditional sliding squares puzzle was adapted to the metaField. In this game, the image is broken up into 4 by 6 grid with one piece removed. When a person steps on a piece of the image that is adjacent to the vacant image, that piece slips into the vacant slot. In doing so the person can break up or reassemble the pieces of the puzzle to make the picture whole.

This work had an interesting visual aesthetic but proved problematic in terms of scale. This game is interesting to play when you have full view of all the pieces, such as when you are holding the small original version in your hand. This game did not scale well to the 16ft by 12ft format for a number of reasons. The most obvious problem is that it is impossible to see all the pieces at once if you are standing in the middle of the floor. Furthermore, the low viewing angles make some of the far away pieces hard to identify. These factors make it difficult to

Figure 38: Puzzle.

develop a game strategy, and thus creates a frustrating experience. On the other hand it demonstrated the applicability of gaming software to this configuration.

The design and implementation of the Puzzle was collaborative activity involving the equal participation of Adriana Vivacqua, Michael Hlavac, Daniel Stevenson and the author.

metaCity Sarajevo

In a configuration similar to the Interactive Cinema's Cinemat, metaCity Sarajevo combines the metaField with an adjacent, vertical projection screen. A map of the former Yugoslavia with Bosnia-Herzegovina at the center is projected on the metaField. A virtual three-dimensional model of a city is projected on the wall portion with Web pages pasted on the surfaces of the buildings. When a person walks on the territory surrounding Bosnia-Herzegovina, the region they entered on changes color, indicating a particular political inclination. When the person then moves onto the Bosnia-Herzegovina portion of the map, it changes color and motif simultaneously. As this happens one of the buildings on the three-dimensional city model rotates and moves forward to prominently display a Web page containing information sympathetic to that particular political orientation in three-dimensional space on the vertical screen. All the different directions for entering Bosnia-Herzegovina invoke Web pages with different political spins on them. For example, if one entered Bosnia-Herzegovina by walking over Serbia, the Web page displayed would be sympathetic toward the Serbian cause; if one walked over Croatia then the Croatian cause would be favored in the text of the Web site.

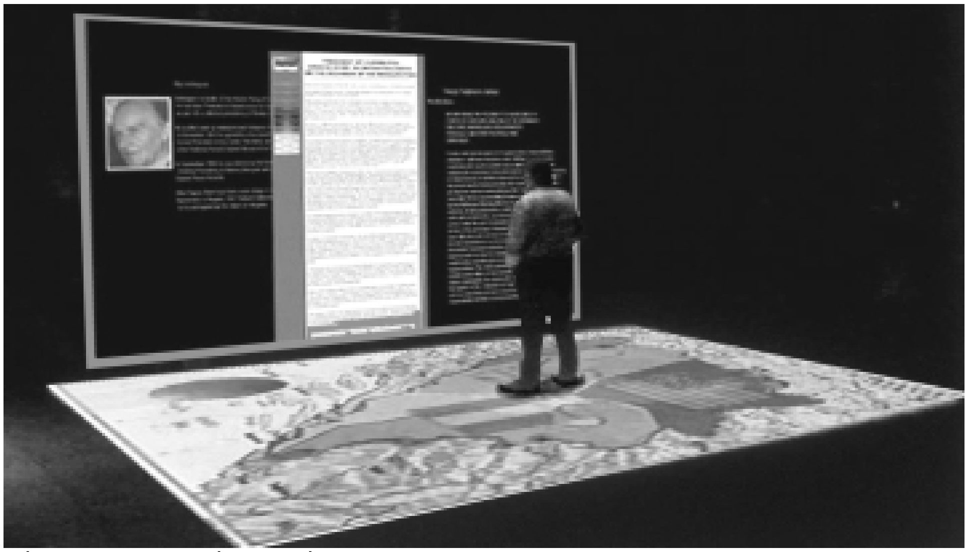


Figure 39: metaCity Sarajevo.

Many interesting observations we derived from this configuration. One of the most obvious yet most startling revelations was the apparent appropriateness of projecting flat horizontal imagery onto flat horizontal surfaces. It became evident that placing a large map on a horizontal surface rather than a vertical one made it considerably less abstract. The large scale of the horizontal map enhances this effect further. The second striking feature about this configuration lies in the obvious potential of merging the floor imagery with the wall imagery, suggesting to the possibility of highly immersive applications without a high degree of confinement as is the case with other immersive systems that will be discussed in the following chapter.

The content concept behind metaCity Sarajevo was provided by Media Lab research scientist Ron MacNeil. The technical implementation of *metaCity Sarejevo* was accomplished through the fusion of the metaField with the *City of News* software; which is an immersive 3-D Web browser developed by Media Lab research assistant Flavia Sparacino. *metaField* software was developed by the author to control the floor graphics while sending information about the location of the user to a second computer running the *City of News* software on the vertical display. All customization of the *City of News* software to display the appropriate Web information was performed by Flavia Sparacino.

metaCity Sarajevo was submitted and accepted to Ars Electronic 1998 *InfoWar* in Linz Austria where it was presented in video documentation.

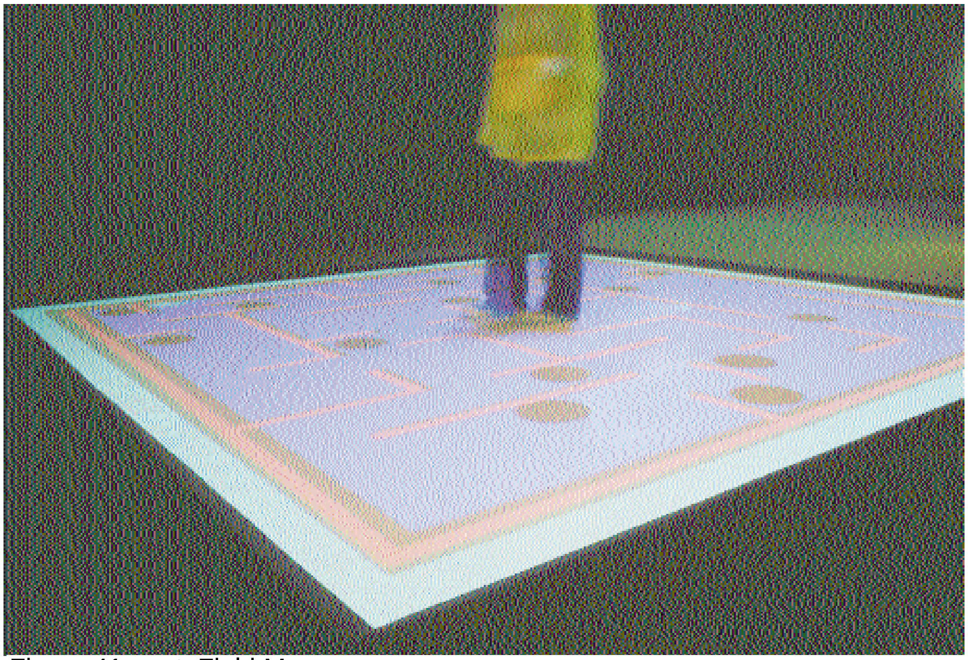


Figure 41: metaField Maze

Maze

The *Maze* was the most successful application developed for the *metaField* by a large margin. It consists of a large scale, virtual recreation of a well known toy. The original version consists of a lap-sized shallow box with knobs on two sides. On the surface is a labyrinth with walls sufficiently high to restrict the movement of a standard-sized marble. The labyrinth is interspersed with holes big enough to swallow the marble. The two knobs are used to tilt the surface level on two perpendicular axes. Thus, by manipulating the two knobs, the player can drive the marble through the labyrinth while attempting to avoid the holes. If the marble falls through a hole the player must start over.

Figure 40: Traditional maze game.

The metaField Maze is a large virtual version of this game that requires you to move your body across the floor space rather than turn knobs to control the path of the marble. This is accomplished by projecting a three dimensional model of the game on the metaField floor. When the player moves in any particular direction, the model will tilt accordingly in that direction, as if it were a large model of the original game pivoting on its center point. When the model is tilted in a given direction, the marble moves in that direction as anticipated. The result is a highly engaging experience and is arguably more fun than the original laptop version.

This application succeeds on a variety of levels. It makes use of the three dimensionality of the projection, but projects an object that has only very shallow relief. In maintaining this shallow level of relief, the player gets the illusion of the third dimension but does not suffer from the distortion and detachment experienced in the Walkaround Data application, where the projected image went into deep three space. From this it was revealed that although the oblique viewing angles imposed by sheer geometry of the metaField configuration imposed severe limits on the extent to which a three-dimensional object could be projected convincingly, the third dimension could still be employed effectively if maintained in low relief.

One of the key aspects of this application is that it creates a strong and instant association between the kinesthetic activities of the player and the simulated kinetics of the game. This tight bond between real and virtual properties goes a long way in erasing the technological presence of the installation.

As the conventional version of the game is so universally known, most players fully understand the concept at first glance and are eager to engage. Players who apparently had no familiarity with the game could figure it out within seconds. Thus this application effectively reduces the threshold of engagement both in its physical configuration: one simply has to walk onto it, no enclosed spaces, no special gear, and in its content: the game is either familiar, or otherwise highly intuitive.

Other interesting factors are observed. Upon engaging in this installation, the players have no choice but to develop a strategy, and then act upon this strategy by using the full mobility of their bodies. The need to engage both the body and mind in a simultaneous concerted effort has powerful effect of inducing an instantaneous and highly focused state of concentration sometimes referred to as a *flow* experience.   Thus the player's state of engagement is profound, further diminishing the presence of the technology involved; a highly desirable quality.

The metaField Maze software was implemented by the author. This software is based on public domain software made available by SGI.
The metaField Maze was exhibited at the Boston Computer Museum and was part of Interaction'99 an interactive art exhibition in Japan in March 1999. In August 1999 it will be part of the Emerging Technologies exhibition at SIGGRAPH'99 in Los Angles

4.1.2 *Suspended Window*

"Suspended Window" is a site-specific interactive art installation done in collaboration with Korean video artist Jay Lee. It attempts the fusion of physical characteristics of a site with parallel computer-generated themes in the form of dynamic computer generated graphics.

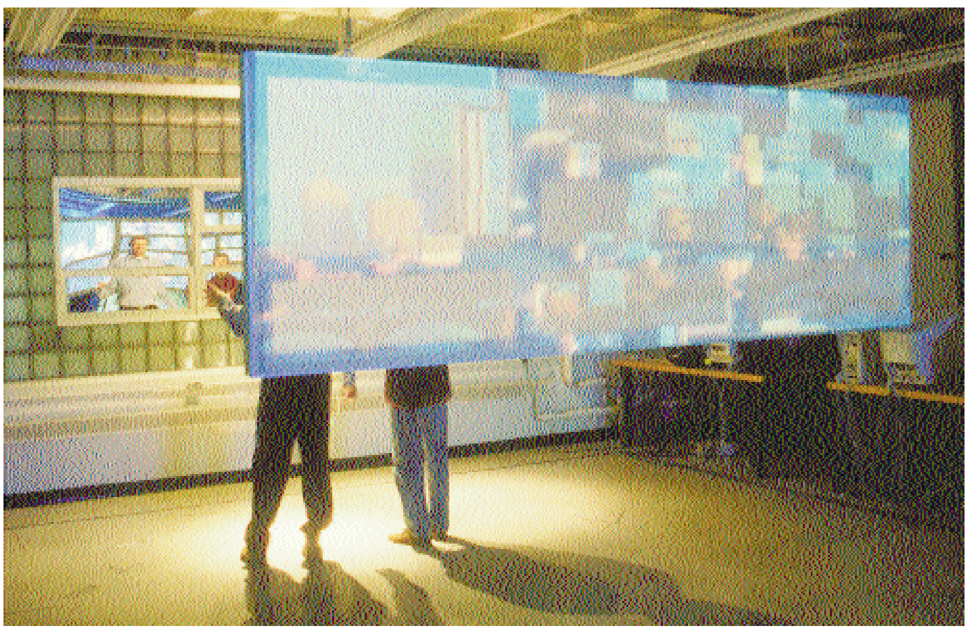


Figure 42: Bill Keays/Jay Lee, *Suspended WIndow*,1998.

4.1.2.1 Site and Objective

The site that provided the impetus for this project is in the Center for Advanced Visual Studies at MIT which is on the third floor of a renovated factory building in Cambridge. On the East wall of the central area is a conventional horizontally biased window, subdivided into 8 sections. Interestingly, this window is nested in a semi-wall of glass blocks, which are encased in the wall; window within a window . This odd configuration seemed to draw attention to the function of the window as a boundary between two discrete spaces. The doubly-tiered configuration of the window invoked the notion of de-laminating the membranes of a boundary. We conspired to do so through an overlap of real, optical, and virtual spaces.

Figure 43: Site of *Suspended Window* in daylight.

4.1.2.2 Design and Implementation

To accomplish this objective, a second window frame, of similar proportions and construction was created and suspended inside the building directly facing the original window at a distance of 15ft. The window panes in the suspended window were substituted for a semi-translucent material suitable for rear projection. The glass panes on the original window were covered with mirrors. A video projector was used to cast its image upon the outside of the suspended window. A video camera was mounted above the suspended window and pointed toward the real window. This video camera transmitted the images of people walking in between the two windows to the computer. The area in between the two windows was the designated interaction zone.

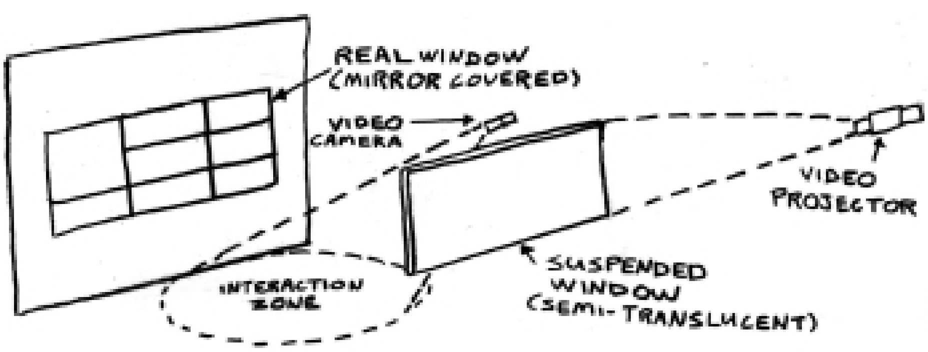


Figure 44: Suspended Window technical configuration.

The video image was used in two separate functions: the first was to locate areas of activity in the interaction zone; the second was to infuse the images into the content of the projection. When the interactive zone was at rest, the image projected on the suspended window was of the Boston skyline; a view similar to what one might have seen looking out throughout the original window during daylight. When a person walked in between the two windows, the skyline image would break up into squares in a fluid and elastic manner in the area on the window corresponding to where the person was standing. This was accomplished by using vision software with the input video to determine the location of the people. The fragment squares were of approximately the same dimension as glass blocks surrounding the real window. During the time that the image breaks up into squares, a second image is revealed, that of a reverse image of the input video stream, thus allowing the viewers to see themselves momentarily through a video mirror. The layering effect is enhanced by the fact that whole effect is visible through the real mirrors superimposed on the original window.

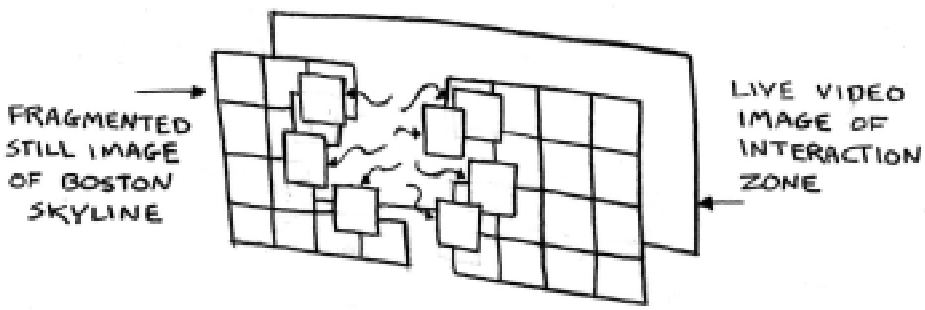


Figure 45: Exploded view of projected image in *Suspended Window*.

4.1.2.3 Software

The software component of this installation was created on a Silicon Graphics Octane in Java using *acJava,* a graphical 3-D programming tool kit developed by the Aesthetics and Computation Group at the Media Lab. The effect is created by positioning two images in space, one slightly ahead of the other on the Z-axis. The rear image consists of the raw input video stream. The front image is a still of the Boston skyline. This still image is segmented in software into an array of evenly sized square sections. Each segment is connected to all of its neighbors through invisible virtual springs. Thus, the segments and adjoining springs make up a highly elastic matrix. Disturbances to this matrix are introduced when movement is sensed in the video image. Movement is detected by comparing the video images from one frame to the next. The movements detected are introduced to the image matrix as repulsive forces. Wherever there is movement, the image segments in that region are pushed away, tugging on their neighbors in the process by means of the virtual springs creating an altogether natural flowing elastic effect in the overall image. Wherever there are gaps created in between the segments due to this movement, the continuous video image on the second level is revealed.

4.1.2.4 Impact

This installation invited subjects to explore a fictitious space created through the delamination of existing boundaries. The gap in between the two windows denotes the space; the optical effect created through the use of multiple physical and virtual layers in a intricate configuration activates the space.Thus, the normal functioning of the window is suspended and viewers find themselves hovering between the strata of this fictitious space. Their every movement creating organic disturbances in the layers and bringing attention to the nature and function of spatial boundaries, real and virtual.

The physical construction of the Suspended Window was performed by Jay Lee and the author. All software written for this installation was done by the author in Java using the acJava tool kit developed by the Aesthetics and Computation Group at the Media Lab.

Suspended Window will be exhibited at TechnOasis, the art show at SIGGRAPH'99 at the Los Angeles Convention Center in August 1999.

4.2 Physical Prototypes

The works discussed thus far have all made use of the high-bandwidth input/output(I/O) capabilities of common computers, namely video input and output, in conventional configurations. That is to say the video input capability has been used by analyzing images from a camera pointed into a normal 3-dimensional space, and the video output capability has been used to project video images on flat surfaces.

It is important to point out that although common computers come equipped with various input and output devices, such as keyboards and mice none other than the video-in and video-out can be considered high-bandwidth. Video I/O entails hundreds of thousands (if not millions) of discrete values of color and intensity processed at a rate of up to 30 times per second. Evidently the bandwidth is numerous orders of magnitude greater than a device such as a keyboard. This high-bandwidth is necessary because the essence of video, continuously changing fine-resolution images, demands it. New prototypes that make alternative use of this high-bandwidth capacity are discussed here.

4.2.1 *Tangible Media*

4.2.1.1 Background

Before getting into the technical details of these prototypes, it would seem appropriate to establish the motivation for this course of investigation. The impetus is derived from the unsatisfactory qualities that are observed in the use of our media in conventional means. These can be observed both in interactive art applications and in general purpose computer applications, the standard computer "desktop" serves as an example.

The universally known computer desktop, consisting of a series of windows containing text and images controllable by mouse and keyboard, is a metaphor for our real desk tops, covered with paper and writing implements and various other materials. This seeing and pointing configuration was invented by Xerox in the 1970's and become massively popular in the mid-eighties with the massive distribution of personal computers. It represents an efficient means of managing computer-related tasks given the very limited I/O devices available. Although it has become universally used it continues to be representative of a barrier between the users and their computer-related intentions. A course of research called *Tangible Media* has come into prominence which seeks precisely to challenge this well established notion of an interface. Hiroshi Ishii of the MIT Media Lab is a leading proponent of this research field; on the subject he states:

We live between two realms: our physical environment and cyberspace. Despite our dual citizenship, the absence of seamless coupling between these parallel existences leaves a great divide between the worlds of bits and atoms. At the present, we are torn between these parallel but disjoint spaces.[7]

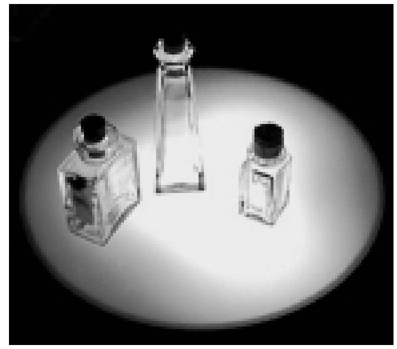


Figure 46: *Music Bottles*, Hiroshi Ishii, tangible Media Group.

In an unrelenting effort to address this situation, Ishii and his Tangible Media research group have created a large number of physically oriented prototypes that attempt to diminish the *divide* between the real and the virtual; music bottles is one such example. When at rest, there is no sound or light emanating from this device. When a user places a bottle on the center disk, it illuminates with colored light. When the cork is removed from the bottle, music from one instrument is heard. When a second bottle is placed on the center disk and the cork is removed, as second instrument is heard in accompaniment with the first, and so on.

Systems such as this one present an altogether different metaphor for manipulating virtual entities. In the former system, the mouse and keyboard act as an omni-present coding/decoding device for dealing with virtual entities; an interface shaped mostly by archaic technologies and standards (the keyboard for example), and paying no attention to the content of the interaction. In *Music Bottles*, a self evident metaphor of a bottle is represented as the container of something, in this case music. To activate it, the person removes the cork, just as we do with innumerable other physical materials. The act seems natural and the feedback is innately gratifying; a very tight association is created between real and virtual entities.

The same applies in the creation of interactive art. Although success and quality of computer-based works using conventional I/O cannot be overstated, vast territory remains unexplored by reconfiguring conventional systems. Elaine Brechin is an artist and researcher at Interval Research Corporation in California, who like Hiroshi Ishii, was struck by the lack of tangibility, and lack of tactile quality

7 Ishii, Hiroshi and Ullmer, Brygg, *Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms*, CHI'97 Conference Proceedings, 1997, p. 234.

of computer-based media. With respect to interactive art, she states the following on this issue:

The narrow bandwidth provided by a keyboard, a mouse and a relatively low-resolution screen leads us away from the physical world and reduces our sensory palette.... We are left with a connection between the creator, the material, the tools and the audience that is often impersonal, distant, and impoverished.[8]

Figure 47: Elaine Brechin, *Windgrass*, 1998.

Her installations such as *Windgrass*, attempt to address this. This installation consists of an array of tiny incandescent lights mounted on the tips of flexible rods sitting upright in a semi-spherical vessel. Mixed in with the light rods are temperature sensors. When a person blows or fans the object, changes in air temperature are detected. When this happens, the lights begin to vary in intensity to forms waves moving across the surface just like the ripples formed by wind over water. As the the waves intensify, the whole object begins to rock gently on its semi-spherical base. This work is notable in the way that it creates a tight feedback loop between the actions of the viewer and the response of the device. Although the work is evidently and completely technological, once the viewer engages this device, notions of technology quickly dissipate in favor of notions natural phenomena. The way in which this work eliminates the notion of interface is a much sought after quality for interactive artists.

As previously mentioned, the high-bandwidth capacity of video I/O provides the potential for innovative interface design. This is illustrated in work by Tom White of the MIT Media Lab which uses the sense of touch called *Liquid Haptics*. White developed a system using a bladder of liquid in conjunction with a video camera to create an input device. In such a device, a bladder filled with a dark, semi-opaque fluid, such as soy sauce sits horizontally on a glass plate. Under the glass is a video camera attached to a computer. When a person manipulates the bladder with their hand, the amount of light visible to the camera below changes according to the area and amount or pressure applied. If they press hard, bright light will come through, if they press lightly, only a slight glow will come through.

8 Elaine Brechin, *Windgrass*; from *the Interaction'99*, cur. Itsuo Sakane, IAMAS, Gifu, 1999, p. 40.

White's liquid haptic device was used as the interface to *Stream of Consciousness*, an interactive art installation created with Dave Small. In this installation, the liquid haptic interface is used to control the flow of words which appear to be floating on the water which cascades down a fabricated waterfall into a small pool. The more pressure is applied to the bladder, the more the words conglomerate and reproduce. The liquid aspect of the interface creates a subtle harmony with the flowing water. The words that seemingly float on the water are projected from above. Through software their movements are designed to reflect the natural oscillations of leaves floating on water, thus creating a seamless bond between the projected image and the projection surface.

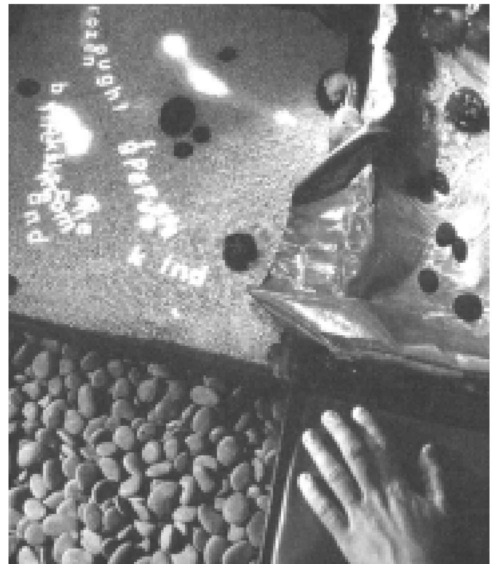


Figure 48: Tom White, Dave Small, *Stream of Consciousness*, 1997. Liquid-haptic interface visible at lower

The works described so far in this section present a mind set for prototype development. The principle objective of the works described in following section is to create interfaces that establish a high level of affinity between the actions of the user and the graphical elements on the computer screen. This exercise aims to diminish the boundary between these two notions by attempting to merge physical properties of the interface with intellectually perceived properties in the displayed model. In this effort, two models are proposed: tension cube and membrane interface.

4.2.1.2 Fabric Membrane Interface

In what could be considered a variation on Tom White's liquid haptic interface, a section of stretchable fabric (Lycra) is installed, in tension, over an upright rigid frame. The membrane is placed alongside the computer display it will control. Behind the membrane is placed a video camera pointed toward the membrane. A light source is placed in front of the membrane. The user controls the display on screen by pressing gently into the fabric. When the interface is in use, changes in light intensity occur on the backside of the membrane. These changes are observed by the video camera and are analyzed by the running program.

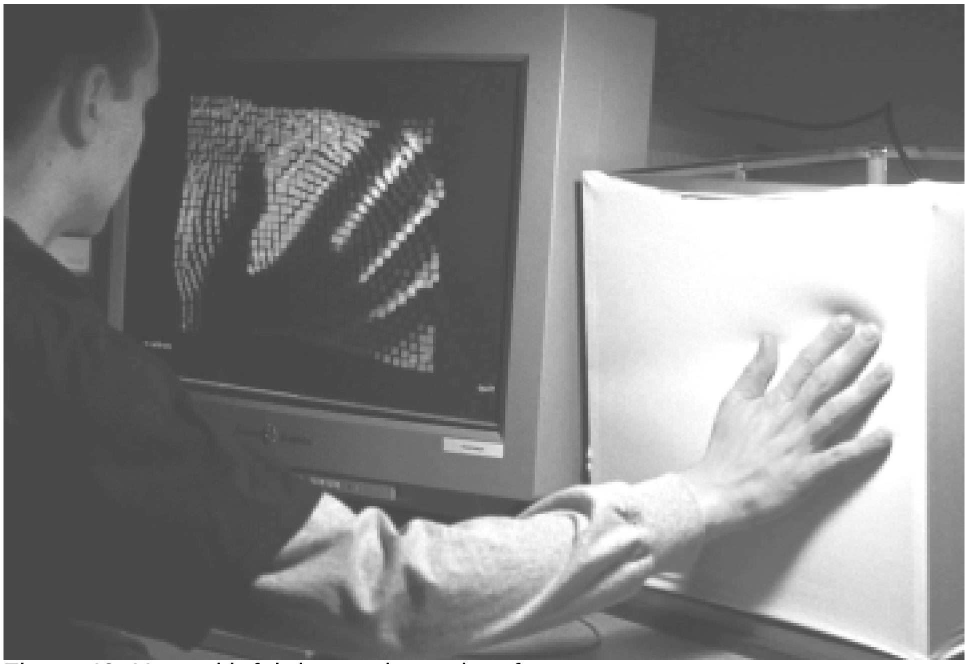


Figure 49: User with fabric membrane interface.

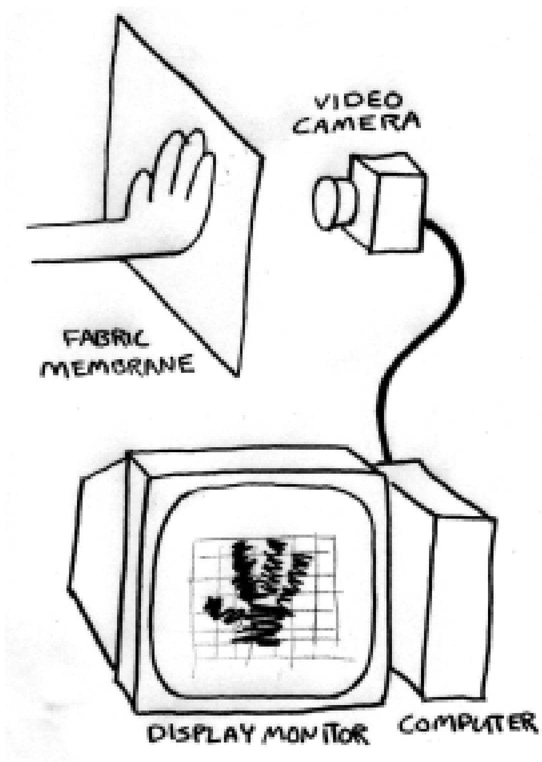


Figure 50: Diagram of fabric membrane system configuration.

The display component of this program consists of a matrix of squares positioned in three-dimensional space. The surface of this array of squares corresponds to the area of the membrane interface. The squares are assigned properties of motion that mimic the physical properties of the fabric of the membrane. More specifically, each square is attached to each adjacent square by a virtual spring. When one square is moved, the adjacent squares will follow suit as if a real spring were in between them.

When the user pushes in on the surface of the membrane, squares on the display in the corresponding region are moved along the negative Z-axis accordingly. As all the squares are in an interconnected network of springs, the whole image on the screen assumes a coherent elastic behavior that works synchronously with the physical membrane at the users fingertips. The software for this application was written by the author using acWindows, a 3-D development tool kit created by the Aesthetics and Computation Group at the Media Lab.

4.2.1.3 Tension Cube

A plaster cube is suspended in space 3 feet above the ground by six cables. The cables are anchored visibly to the floor and ceiling with stretched fabric. Attached to the cube is a motion and orientation sensing device. Motion in the Z, Y and Z directions can be sensed as can rotational movement in all three axes.

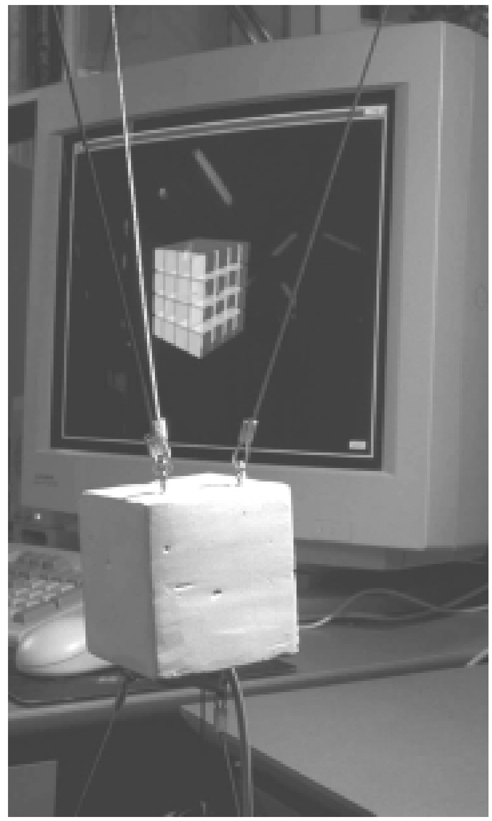


Figure 51: Tension Cube.

On the screen is a three-dimensional model consisting of a 4 by 4 array of semi-translucent cubes. At the center are colored slabs which travel in the gaps between the cubes. They are color-coded red, blue and green, to indicate the X, Y, and Z axes. When the suspended cube is moved along any of the three axes, the corresponding slabs move in unison.

The key aspect of this device is that its aesthetic configuration is such that the user will recognize the physical dynamics of the interface upon visual contact. When using it, a tight, effortless association between the physical gestures of the user and the activity on the screen, thus diminishing the barriers normally present in interface design.

All aspects of the Tension Cube were executed by the author. The software was written on an Intel-based PC using Visual Basic and TGS Inventor.

4.2.2 *Alternative Input Methods*

As mentioned earlier, for all its merits, we should not limit the high-bandwidth I/O video capacity of computers to simply transmitting two-dimensional images. Systems and prototypes discussed so far, such as liquid haptics and fabric interface suggest a broader range in the use of video I/O. This section will describe prototypes that make alternative use of video input.

4.2.2.1 Fiber-Video

At a resolution of 640 by 480, an incoming video image carries over 300,000 discrete units of information in terms of color and intensity. Refresh rates ranging between 10 and 30 frames per second clearly make this a very high-bandwidth input channel. Normally all this information is part of a single coherent image, but it need not be.

An alternative variety of input can be created by coupling bundles of optical fibers to a video camera. Instead of carrying images of its immediate surroundings, the camera carries an image of the light emanating from the ends of a large number of optical fibers as described below.

A bundle of optical fibers is truncated cleanly at a right angle and placed orthogonal and in close proximity to the plane of vision of a video camera. The camera is attached to the computer through a standard video port. Software on the computer is created such that the variations in light observed in each individual fiber can be read and interpreted. This makes it possible for an unmodified, standard computer to accept a large number (10,000 or more) of discrete inputs of intensity and color range. This vastly supercedes the ability to accept discrete values from other conventional input devices. The source of input can be derived from any direction, from any conceivable device that has the ability to control the light going into one or more optical fibers. The fibers do not require any power, do not generate any heat and can be tunneled into hard to reach areas. An analogous configuration for creating output will be described later.

4.2.2.2 Fiber-Video Input Prototype 1

In this prototype, a bundle of 37 optical fibers was integrated into a block-shaped interface made of Lego. 36 of the fibers entered the larger block where the fibers terminate flush on the surface of the object on the inside of each of the square slots. Three other fibers go into a smaller block with three thumb wheels on it. On the other end, the fibers are cut flush and coupled to a video camera.

On the computer screen is a box consisting of a series of panels. The user uses the block interface to control the block on the screen. This is accomplished by blocking the light entering different sides of the interface block by placing fingers in the square slots. When this is done, the corresponding component on the display cube is activated. When the wheels on the smaller cube are rotated creating oscillations in the light level entering a given fiber and the cube on the screen rotates on the corresponding axis.

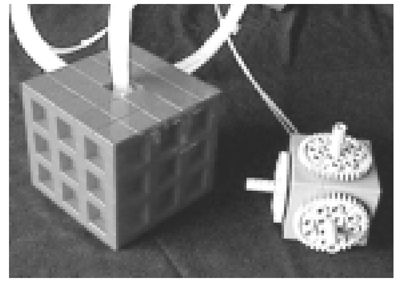


Figure 52: Fiber-Video interface blocks.

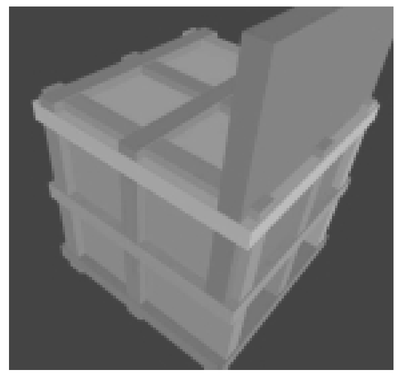


Figure 53: Fiber-Video on-screen graphics.

This prototype served as a working model of the fiber-video concept in that the camera was reading information that was not in a two-dimensional plane, and that devices to control the light input could be easily devised. It also demonstrated the need for a more robust fiber-to-camera coupling mechanism.

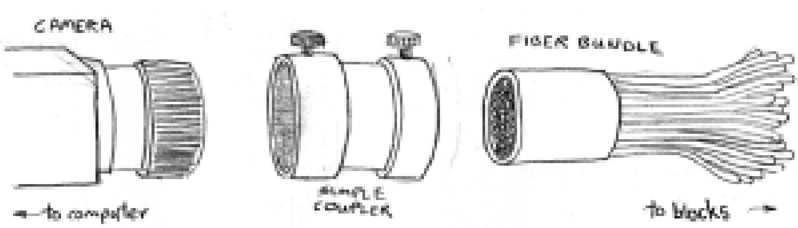


Figure 54: Diagram of fiber/video camera coupler.

4.2.2.3 Fiber/Video Input Prototype 2

Having established feasibility with the first prototype, a second prototype was devised to better illustrate the principles of the concept, and to introduce a coupling device that was more robust and where the incoming fiber bundle would be fully coherent and addressable.

The second prototype also used a cube configuration, this time with 125 input fiber segments. In order to fully reveal the configuration, the device was made of clear plexi-glass, revealing all the fibers inside and how they terminate at the surface of the cube.

The coupling was completely revised. The fibers are placed before the camera in a regular matrix. Where before a specific mapping was required for randomly bundled fibers, here individual fibers are located by their position on the matrix. Furthermore, the matrix plate on the camera mount is interchangeable to enable alternate input devices to be used.

The display created for this interface consists of a three-dimensional cube segmented to reflect the positioning of the input fibers on the input device. When the user alters the amount of light entering one of the fibers by placing a finger over it, the corresponding square changes in color and brightness accordingly; this change is accentuated by the movement of the relative panels. If the ambient light in the room was bright, the whole cube would become large, if all fibers were blocked simultaneously, it would become small.

All software used in the fiber-video prototypes was written by the author on SGI computers using C++. Prototype 1 also used the Inventor 3-D tool kit. Prototype 2 used the Performer 3-D tool kit.

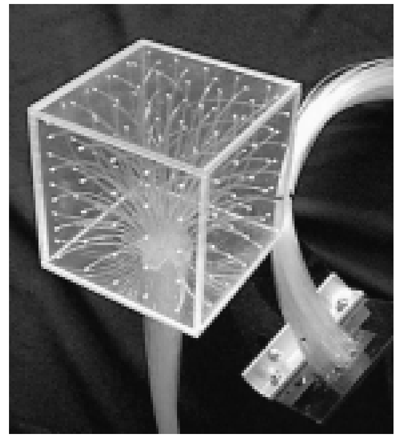


Figure 55: Input cube with fiber matrix mount in background.

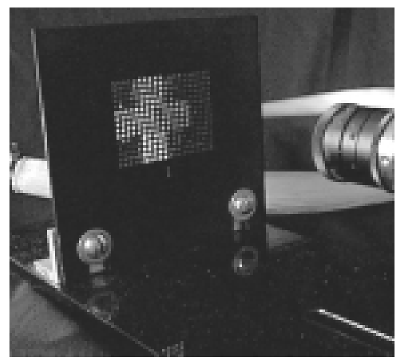


Figure 56: Mount with camera pointed to input fiber matrix.

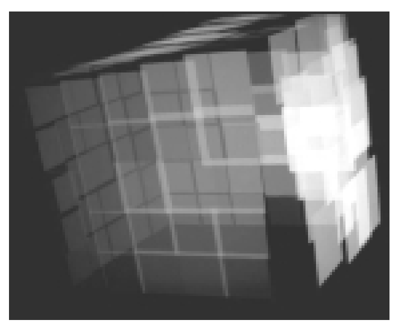


Figure 57: On-screen application driven by fiber-video input device.

4.2.3 *Three-Dimensional Display Systems*

4.2.3.1 Background

In the course of doing research on the possibilities of reshaping the source and destination of the light coming in and going out of video devices, the notion of creating a three-dimensional light display arose. The quest for creating the ultimate three-dimensional display system has been the equivalent of the Holy Grail in the computer interface industry; many radically different approaches have been taken, all have strengths and weaknesses. We begin by discussing holography and stereo-vision systems.

The most universal type of three dimensional display is without question, the hologram. Invented by the Hungarian electrical engineer Dennis Gabor in 1948, holograms described briefly are created through the splitting of a laser beam, reflecting part of the beam off a designated object and then reuniting this with the reference beam. When the two beams reunite interaction patterns in the light are formed, these are then recorded on photographic medium. The result, normally viewed as an image on a glass plate, is something reminiscent yet totally different from a photograph, because when the angle of viewing is changed, so changes the angle of the object in the hologram. The optical phenomenon of the hologram which seems to exist in defiance of pure logic, is described as follows by art historian Frank Popper:

Unlike a normal picture, a hologram manifests itself as something that first appeals to the tactile and motor senses. Only through the skillful interaction of the tactile and the visual does it release its holographic image. Only when we hold it in our hands like a mirror and move it back and forth, or when we view it from various angles, is it possible to discover something similar to a picture.

Just as holographic optics brings about a rupture with geometric optics, holographic space is no longer explainable in the sense of classical Euclidian geometry. Unlike perspective space, which left its imprint on three-dimensional visualization and our conceptualizations in general, holographic space is not as imaginable as a purely mathematical construction but is experienced as an indefinite phenomenon which corresponds to the everyday experience of Postmodern culture.[9]

As with conventional photography, conventional holography benefits from the fine resolution of the emulsive medium in creating strikingly detailed reproductions, but also like conventional photography, it has been confined to representing still moments captured in time, until recently. Significant research has been made recently in introducing interactivity to holography.

9 Popper, Frank, *Art of the Electronic Age*, Thames and Hudson, Singapore, 1983, pp.37-38.

Under the direction of Stephen A. Benton, the Spatial Imaging Group at the MIT Media Lab has created a system for interactive, *haptic holography*[10]. By combining computer generated holograms with haptic input a system was created which, in the tradition of fine craftsmanship, reunites the subtle gestures of the hand with the shaping of objects perceived completely in the round.

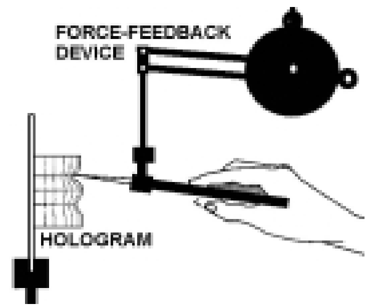


Figure 58: Diagram of haptic, interactive holography device created by Spatial Imaging Group at MIT Media Lab.

A haptic stylus known as the *Phantom* is used to capture input from the user. This device not only traces the gestures of the user's hand, but provides a force-feedback response akin to what might be used in a flight simulator. The simulation of a lathe is used for the purpose of demonstration. When user points the stylus into the region where the holographic cylinder is perceived, the *Phantom* produces resistance where the physical and holographic objects coincide. As the user persists in applying pressure, vast amounts of computing power are used to regenerate the hologram to conform to the position of the stylus. Thus the shape of the computer generated hologram changes as one would expect, behaving similarly to material on a lathe. Again, a tight, well integrated feedback loop is established between the gestures of the user and the visual and haptic feedback recalling the immediacy of the hand of the craftsman and effectively betraying the enormous, underlying complexity.

Another well established technique of getting the three-dimensional effect is through the use of stereo-vision. Here the illusion of depth is created by exposing each eye to different images which are in correct parallax with respect to the position of the viewer's eyes. This type of 3-D viewing device has been in existence since the dawn of photography. One of the founders of the photographic era, William Henry Fox Talbot is know to have exhibited stereograms as early as 1841. But it was not until Sir David Brewster invented a practical viewing device eight years later that the stereogram became widespread. Stereovision has since resurfaced in in all shapes and forms including 3-D cinema and the Viewmaster.

10 Plesniak, Wendy, Pappu, Ravikanth, *Coincident Display Using Haptics and Holographic Video*, CHI'98 Conference Proceedings, pp. 304-311, 1998.

Stereovision was integral to the pioneering enhanced reality system created by Ivan Sutherland at the University of Utah in 1970 (picture on page 18). Here stereovision is used to superimpose three dimensional images over our field of vision. Because the system does head tracking, the synthetic objects appear to be anchored to specific locations in real space. Since then this technology has found its niche in the development of aviation and military technology.

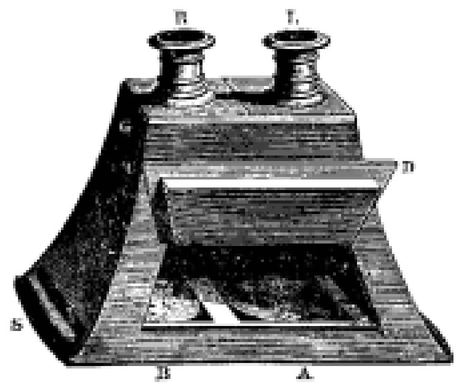


Figure 59: The Brewster Stereoscope, 1856.

Stereoscopic vision is also the cornerstone of most VR systems. One variety works by completely covering up your field of vision with a head mounted device as shown on the left. These systems are commonly combined with other sensory and haptic input for the manipulation of synthetic objects in three-space. Other systems allow for several users to exist and interact within a single VR environment.

Figure 60: VR stereo vision headset by General Reality Company.

A different approach to making each eye see a different image is to interlace the images on a conventional display; i.e. alternate images each time the screen is refreshed which is about 60-70 times per second. This works in collaboration with goggles that have electronic shutters in them that open and close such that each eye always sees the correct image. The goggles are lightweight, self-powered, and untethered thanks to wireless communication with the host computer. This is the viewing technology in use inside the CAVE, the room-sized virtual reality

Figure 61: Users experiencing immersive 3-D environment with shutter goggles in the *CAVE*.

environment developed at the National Center for Super-computing Applications at the University of Illinois in Urbana-Champaign. This landmark facility has rear-projection surfaces on three walls and the floor giving users wearing stereo goggles a fully immersive three-dimensional effect without the disorienting and visually depriving inconvenience of the head-mounted display.

4.2.3.2 Solid-Light Prototype

Although the systems described above go a great distance in resolving the challenge of creating practical interactive three dimensional displays, they do have shortcomings. The technological overhead entailed in the creation of holography generates results that are highly confined, limited in size, and difficulty viewed. The fine resolution of this medium is without equal, but the limitations imposed by its packaging curtail its applicability, particularly for the purpose of creating interactive installations. The verdict for head-mounted displays has been made clear by Myron Krueger and many others with whom the author agrees, that the requirement of wearing this apparatus severely impedes the freedom of both the artist and users. The barrier imposed by having to strap on equipment creates a threshold for engagement which is generally considered to be unacceptable.

Concept

The display described herein was not designed to compete with any existing alternatives in terms of resolution or color quality or practicality. It was designed as a means of taking full advantage of the high-bandwidth capacity of an output video stream through a medium shaped with materials that carry meaning through their own aesthetic. Having experimented with light pipes in the form of optical fibers on several input devices, it followed that a similar strategy could be used for output.

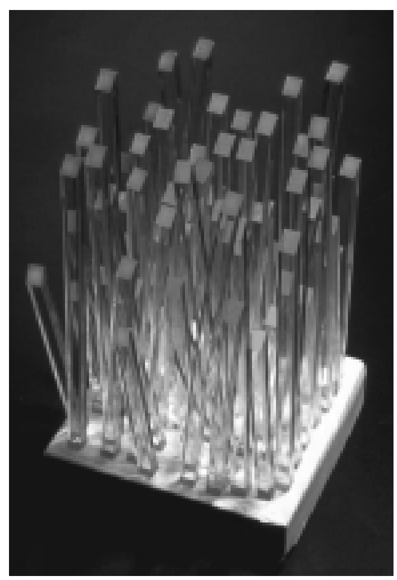


Figure 62: *Solid Light*, small scale prototype shown in non-active state.

In this situation, the video camera is replaced by a video projector, and the fibers are replaced by solid acrylic rods. Although the square 1/4” acrylic rods used in this experiment do not have the efficient optical properties that fibers do, they work effectively as light pipes over short distances. That is to say that if one end of an acrylic rod is polished smooth and the other end is polished coarsely, most of the light entering the polished end will escape through the opposite end, mimicking the behavior of optical fibers. We get a material with a strong visual aesthetic that can be sculpted and has the ability to carry high-bandwidth video output.

The concept of projecting images into a three dimensional array of light pipes is not entirely new. In 1979 Alexander Schure and William Glenn created a similar configuration using optical fibers supported in a solid transparent medium to be used in conjunction with computer display or any other image projecting device. More recently, in 1996, James Veligdan from Brookhaven National Labs developed a display that uses the similar internally reflective light properties of planar acrylic to create an extremely robust 2-dimensional display device. A large number of these acrylic sheets are bonded together and then cut diagonally to reveal the edge section of each plane when looking at the whole perpendicularly. The source image once again is projected into the base. Both these works serve as inspiration for the solid light display; the key distinction of which is that the sculptural properties of the object are now of central importance.

A small scale prototype was created to establish feasibility. In it, an array of eight by eight acrylic rods are cast upright in a plaster mold. The rods are placed at varying angles to give the object an organic crystalline appearance. The rod tips are trimmed at 45 degrees and roughly polished to diffuse light. The upper ends of the rods form a loose 4x4x4 grid in three dimensional space. The underside of the object is polished smooth exposing the bottom ends the rods, and allowing the light from the projector to enter them. The software on the computer is made familiar with the mapping of the rods from the base into 3-D space. Thus it becomes possible to move colored virtual objects through the three-dimensional space of the solid-light display, albeit in a very low 4x4x4 resolution.

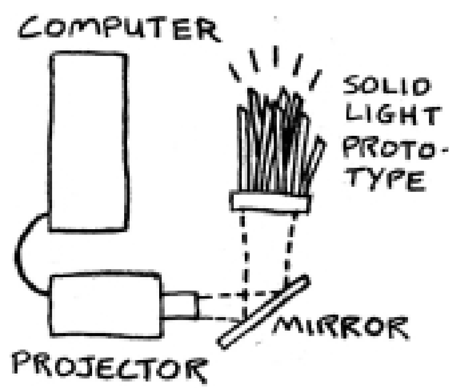


Figure 63: Diagram of *Solid Light* display configuration.

Simulation

The promising qualities of this first device prompted further investigation. Before undertaking the task of constructing a new physical model, software was written to simulate the appearance and functionality of solid light displays of any dimension. An application was created where video input transposed into the solid light display in real time. To get a three dimensional image from video input, a simple interpolation is applied. In a technique devised during the Renaissance, and refined during the Baroque period, roundness of objects is achieved through *chiaroscuro*, or degradations between light and dark portions. The simulation software creates relief in the same way from the input video image. This is accomplished by using controlled lighting and background, and by placing only simple objects before the camera such as a person's hand. With the light at the correct angle and intensity, the parts closest to the camera will have the highest intensity, and those farthest away will have the lowest. In this way, the image of the hand is cast into the low-relief three-dimensional display.

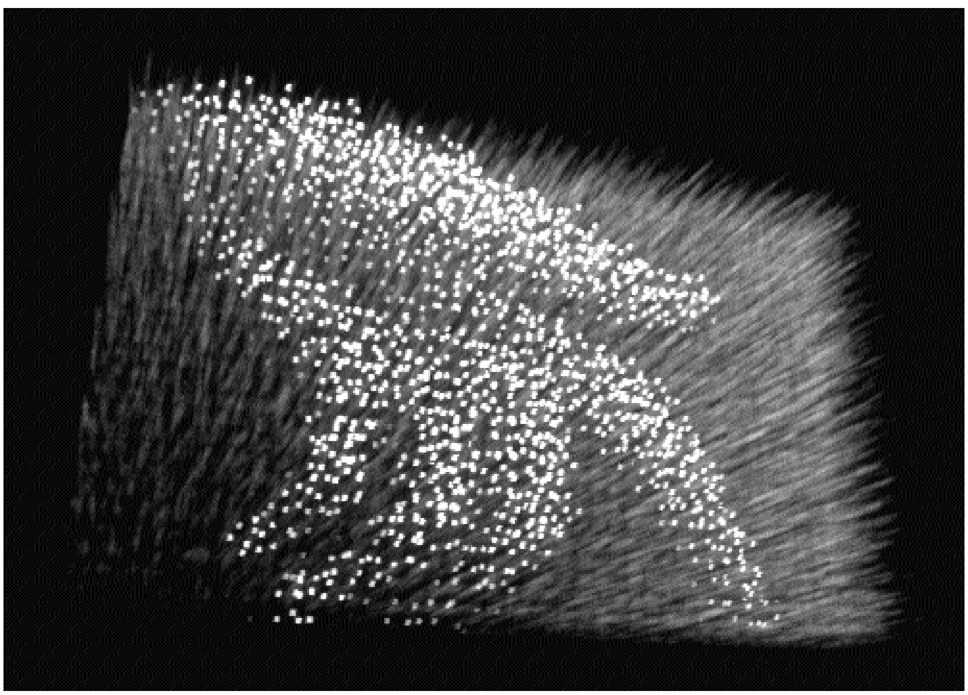


Figure 64: Solid light display simulation with video input of a person's hand.

The simulation in the next figure illustrates the three-dimensional effect by observing the display edgewise. To demonstrate the low relief, a still was taken while the user waved two fingers before the input video camera.

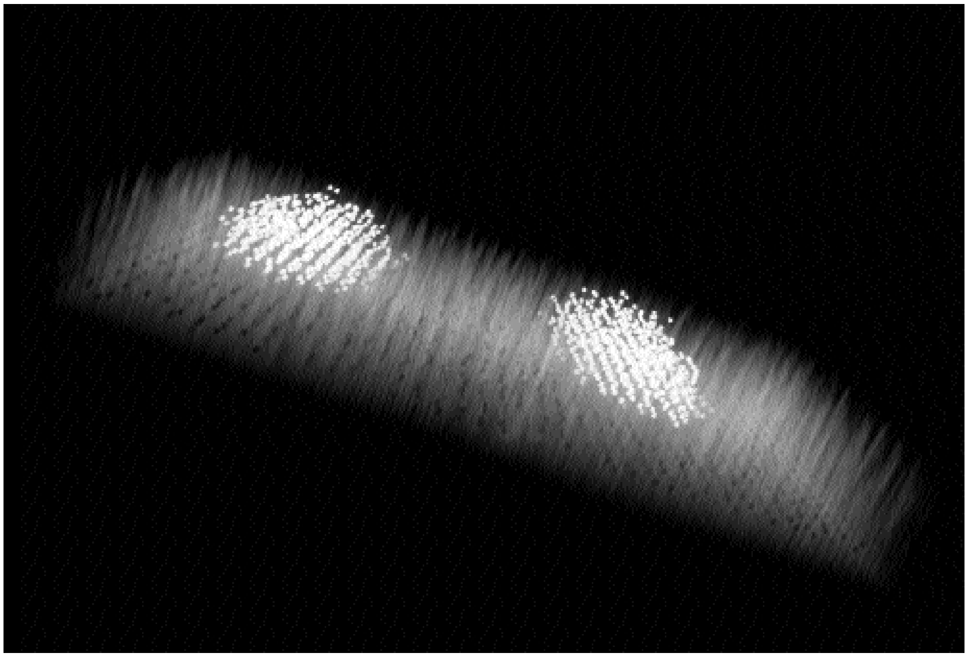


Figure 65: Solid light display simulation illustrating low-relief effect.

Following extensive testing with the simulation software, a specification of 16x24x4 was decided upon. This dimension would be sufficiently large to view identifiable objects and observe relief into the third dimension. As in the original prototype, the top ends of the 1/4” square rods were trimmed at 45 degrees to point the light emitted toward the observer. The top side of the display was also tilted 15 degrees to enhance this effect. Again the rods were placed in randomly tilted positions while maintaining a regular three-dimensional grid configuration. A jig was constructed to hold the 1536 rods in place while the base was poured in epoxy resin. The base was polished, the unit placed upright on a stand, and the projector was pointed into it in a configuration similar to that illustrated in figure 63. As the rod supporting base was made of clear material, epoxy resin, it was necessary to mask the the space between the rods to prevent excessive diffused light from getting through. For this purpose a material was needed with physical properties that would complement the aesthetic of the angular, organic mass of standing rods. A granular, non-abrasive material would be needed; salt was used.

Software

The software used to drive this display prototype worked as follows: the live input image was captured and interpolated into a low-relief(four-pixel depth) three-dimensional model using the technique described in previous sections. This

Figure 66: Live video input.

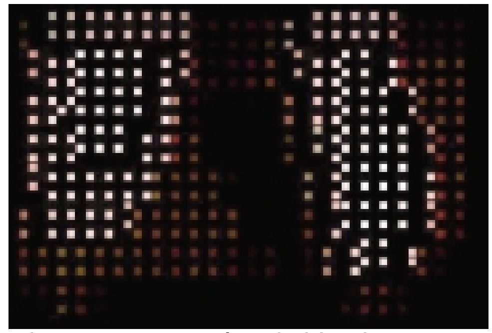


Figure 67: Interpolated video input projected into the base of the solid light display.

3-D data was cast into a two-dimensional matrix where the four-pixel depth was collapsed into four adjacent squares creating a disjointed-looking reproduction of the original video input. This disjointed image is then projected into the base of the solid light display where each square in the projection corresponds to a specific rod of known location and height such that the image appears in the display in correct relief.

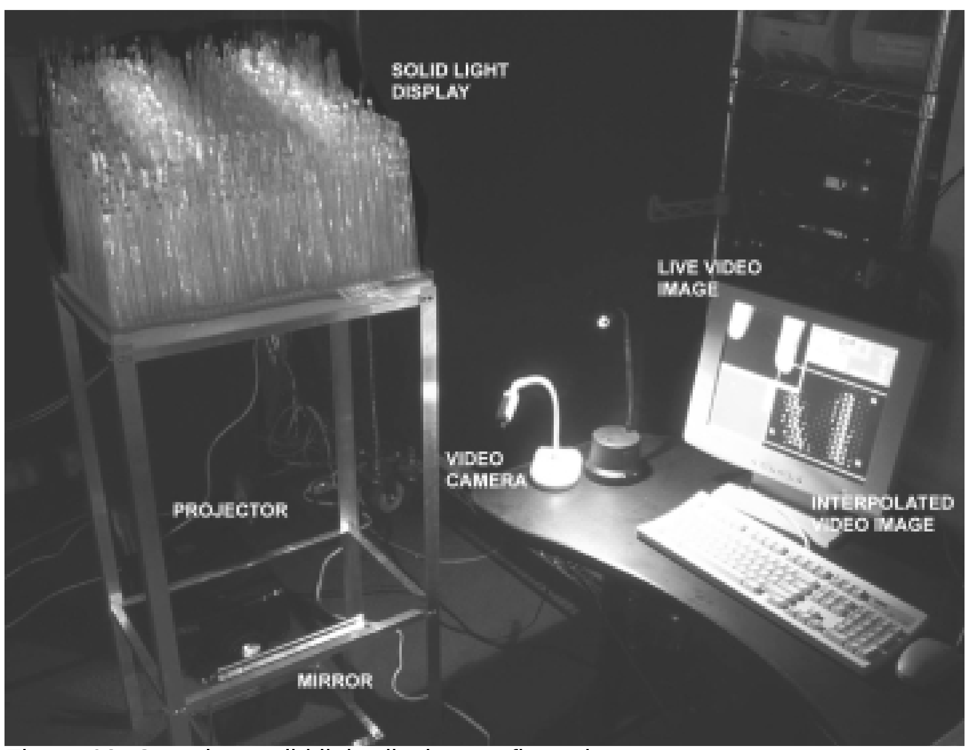


Figure 68: Complete solid light display configuration.

Because this is a peculiar light-based configuration, it is difficult to photograph. Nevertheless the figure below effectively illustrates the complete configuration (for the purpose of taking this image, the person who's hand was before the video camera is removed to expose the entire configuration). In the center is the video camera where the user placed two fingers of a hand before the camera. On the computer screen on the right, the live video image of the person's two fingers is visible as is the interpolated image. The latter is projected into the base of the solid light display with the use of a mirror. The two bright columns of light in the solid light display are the three-dimensional projection of the user's fingers.

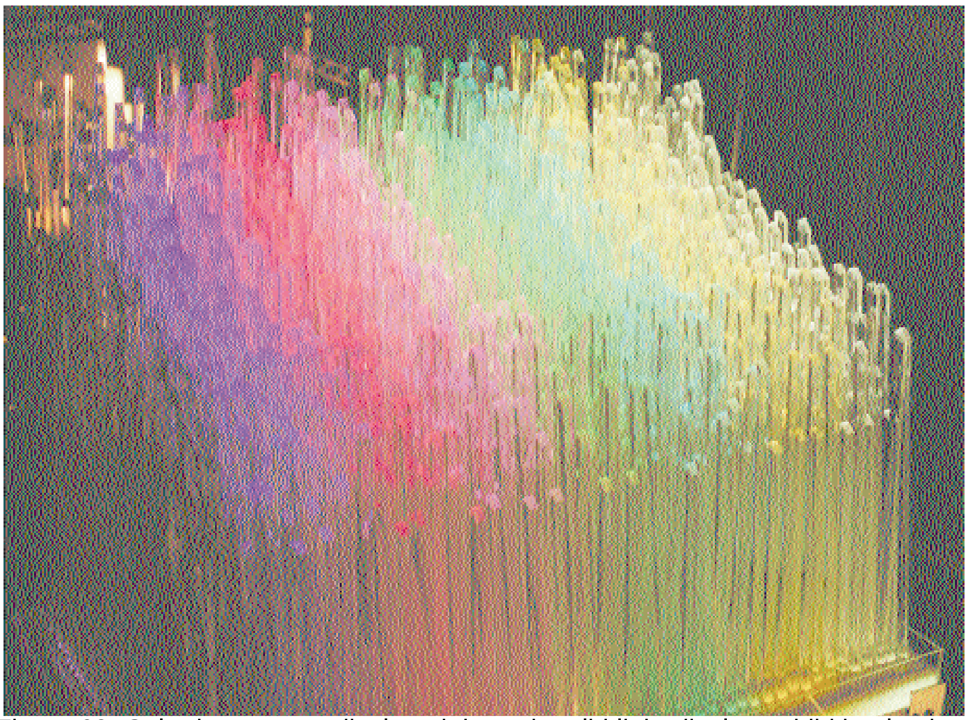


Figure 69: Color bar pattern displayed through solid light display exhibiting luminance and color range of device.

The software developed for the Solid Light was written by the author using the acu development tool kit created by the Aesthetics and Computation Group at the Media Lab.

Observations

The result was a striking and unique display of embodied light. Effects that had not been anticipated in simulation were observed. Most notably, as the entire device is made of sharp angular objects a visual effect of a similar quality was expected, as demonstrated in the simulations. The simulations, however, did not take into consideration the diffused light that would occupy the volume of the device. The result was a soft, luminous, halo-like effect within a hostile jungle of transparent shards; a stunning and highly seductive visual contrast.

The success of this experiment prompts the creation of a large display of this type that makes use of the full resolution of the output video stream. Because this display has a visual aesthetic in its own right, as opposed to being merely a projection surface, it is has great potential as dynamic display in a public art context. A free-standing large-scale version could work with the use of high-powered projectors; an integrated version could work with an LED matrix replacing the projectors.

Application

Although the creation of a large-scale solid light display is beyond the scope of this thesis, this technology was proposed as an integral component to a public art submission made for the new South Korea Telecom (SKT)building in Seoul. This proposal, submitted by Jay Lee and the author in March 1999, will take part in a competition for the mandatory 1% public art budget for the new building, scheduled for completion in late 1999.
The proposal entails the installation of a large solid light display that would cover the ceiling of the lobby. The topography of the suspended rods would be such that it would reflect the geographical topography of the city of Seoul; more precisely, it would be a scaled imprint of the land surface of the city of Seoul.

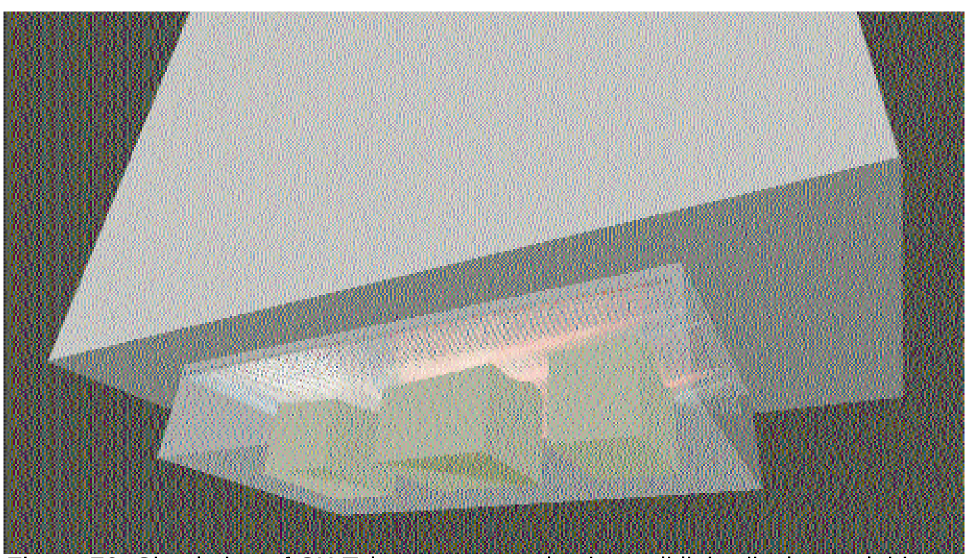


Figure 70: Simulation of SK Telecom proposal using soli light display on lobby ceiling.

Working in collaboration with the SKT data center located inside the building, this display would project a live data model representing the current wireless communication activity over the city (SKT offers solely wireless service). A second feature is layered atop the demographic model: through a special dial-out number arranged by SKT, when a person makes an outbound call from the lobby of the building, a line appears on the ceiling pointing from the position of the caller in the building(which is known through an infra-red vision system), towards the location of the call destination (which is known via SKT data center).

The organic quality of the solid light display creates an interesting metaphor in this configuration. The rods are pointing downward, and are located at the base of the building as if the people below were looking up through the roots of the building and seeing the picture of activity that takes place within the corporation's realm of operation, which is the airspace above the city. The building is thus presented as a lens through which normally inaccessible yet pertinent social information is visualized. It is a data representation model which assumes in the late 20th century same role as Gericault's *Raft of the Medusa*; exposing information to the public in a vivid and engaging method, information that is otherwise inaccessible.

The second feature, where a line is drawn between the caller and the call recipient, addresses more personal issues. When making such a call, the callers will inevitably rotate their bodies such as to align themselves in the direction of the line, effectively pointing towards the person to whom they are speaking. This has the sudden effect of reclaiming social qualities that are lost in long-distance communication. Normally, telecom users make calls with no sense of geographic orientation; the world of global communications is nebulous cloud where notions of distance an direction are stripped away. By drawing a line pointing to the destination of the call, geographic orientation is reclaimed adding a previously inaccessible quality to the interaction. On a more personal level, the fact that the person will be facing the caller has interesting social repercussions. When we talk to people who are in our immediate presence, we naturally face each other as visual clues obviously lead to a richer interaction, as the does the notion of knowing where the other person is. Thus we speak towards each other, another social quality which is lost through long-distance communication technology. By orienting one's body toward the destination of the call one reclaims a small part of the intimacy lost through the overwhelming presence of technology.

5 Analysis

6.1 Review of Accomplishments

With respect to model and prototype development the accomplishments of this thesis can be grouped into two categories as follows:

finished works	operational prototypes
metaField	Tension Cube
Suspended Window	Membrane Interface
	Fiber-Video
	Solid Light

In the finished works section we find the metaField, more specifically the *metaField Maze* and *Suspended Window*. These works are complete in that they have been exhibited in public and have demonstrated a level of maturity that led to selection in peer reviewed Internationally sanctioned events. More specifically, *metaField Maze* was selected to be part of Interaction'99 in Japan as well as the Emerging Technologies Exhibition at SIGGRAPH'99. *Suspended Window* was submitted and accepted of the TechnOasis Art Show at SIGGRAPH'99.

The *operational prototypes* section encompasses prototypes conceived, designed, created and brought to working form by the author. These works have entailed the necessity of working with a diverse range of materials and components and are developed to the stage where the underlying concept is confirmed, and promising new directions can be readily identified. The Solid Light proposal for the South Korea Telecom building discussed in the previous section makes a case in point.

As the diverse nature of the work produced entailed encounters with a wide variety of materials, processes and techniques, it is useful to rate the work produced under the parameters of transparency, malleability, and complexity.
The lists are arranged in descending order according to the category (*Tension Cube* and *Membrane Interface* are grouped as Tangible prototypes):

transparency	*malleability*	*complexity*
Solid Light	metaField	Solid Light
metaField	Fiber-Video	Tangible prototypes
Suspended Window	Tangible prototypes	Fiber-Video
Tangible prototypes	Solid Light	Suspended Window
Fiber-video	Suspended Window	metaField

The category of transparency refers to the extent to which the presence of the given technology erases itself from the work being presented. Solid Light tops this list because it is a single solid object, with no moving parts and no attachments. Furthermore, the object is physically distance from the computer equpment driving it. This object simply catches light. The object in its inert state has a strong aesthetic quality; when the system is on, it assumes a fascinating, optically seductive quality that does much to erase all presence of technology. On the other end of the spectrum is the Fiber-video. Such is the case because this system is inevitably tied to a host computer via a large umbilical cord of optical fibers. The prototypes presented here entailed on-screen computer graphics, further entrenching the presence of the computer.

The “soft” in software alludes directly to its infinite malleability. The metaField is first here because it is fundamentally a software application; the floor projected upon is featureless and there are no other components involved other than projected light. It is a generic interactive installation in the same sense that a computer monitor is a generic interactive screen. The wide variety of applications developed for the metaField make this point. Although Suspended Window uses much of the same technology, all components are put into a very specific configuration relating to the content of the work resulting in a very rigid configuration.

The physical prototypes all rated higher in terms of complexity. This is because physical prototypes inevitably involve complex and time consuming manufacturing processes, each process demanding a significant level of proficiency. The situation is further complexified by limited access to the facilities required. Furthermore, these prototypes inevitably require a sophisticated software component as well. In the case of the metaField, the hardware configuration is straightforward using existing components. All the sophistication lies in the single task of programming, finding itself therefore at the lower end of the list.

6.2 Plotting a Course

Through the numerous activities undertaken in the course of this thesis, a strategy for further work emerges. Works produced have demonstrated potential both in terms of marketable research, and in artistic production. The *metaField Maze* for example, has been presented both at art exhibitions, and and at technical conferences. It has illicited interest from Mattel Corporation as marketable technology and the generic *metaField* con figuration has generated interest in the field of kinesthetics as an engaging device for physical rehabilitation. Hence, an effective fusion is[11] accomplished between professional and artistic activities. Divergent styles of model design have been explored, grouped generally as non-tangible immersive environments(*metaField Maze*), tangible prototypes (membrane interface, tension cube), and sculptural display and input systems (fiber-video, solid light display). Work produced in later stages, such as *Suspended Window* and the SK Telecom proposal anticipate an integration of all models examined.

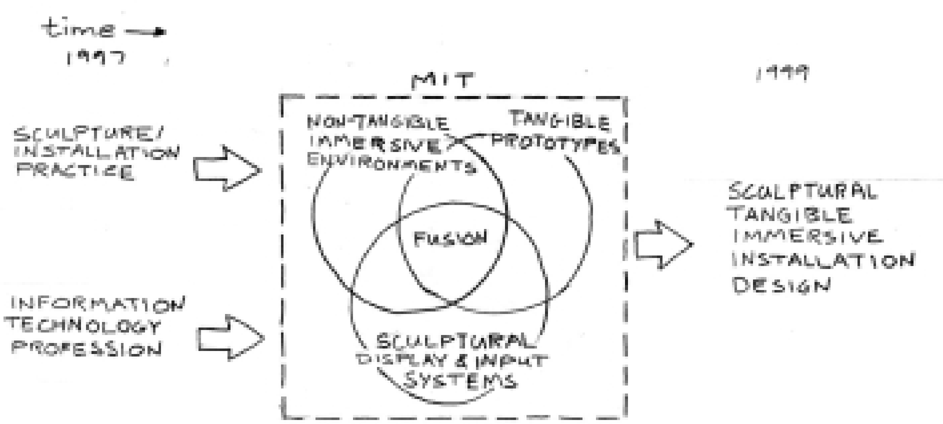


Figure 71: Course of development.

That the works produced with artistic intent in the course of this thesis have also demonstrated marketability establishes legitimacy of the artist within corporate research culture. Herein is defined the role sought by the author. The following section examines the importance of this role within a broader context.

6.3 Arena for Practice

With respect to the practice of art in conventional media such as painting or sculpture, it has been reasonably feasible for the contemporary artist to exist as a self-sustaining entity. In comparison to the technological artist, the logistical and financial requirements of a painter, for example, are relatively minimal. Although it is appalling that any practicing artist should have to live on bare subsistence, for the technological artist, it simply not possible. The cost of the equipment, services and facilities required by the practice demands an altogether new relationship between the artist, community and business. All of the installations created by the author described in this thesis entail the procurement of expensive specialized equipment made possible only through the support of a well-endowed academic unit; elite circumstances. Where then, are the prototypes for the artists of tomorrow?

An early example that comes to mind is that of the Center for Advanced Visual Studies (CAVS) founded by Gyorgy Kepes at MIT in 1967. The following statement by Kepes captures his outlook upon arriving at MIT:

> I discovered with joy a different an inspiringly encompassing and more objective world; with dismay I also found out how uninformed I was about some of the majestic achievements of this century. At the same time, I learned to my surprise how uninitiated some of my scientist and engineer colleagues were when it came to the most basic values of artistic sensibility. Gradually I began to see that the world opened up by science and technology could offer essential tools and symbols for the reorganization of our inner world, the world of our sensitivities, feelings and thoughts. Furthermore, I came to believe that artists and scientists would be equal partners in this great transformation.[11]

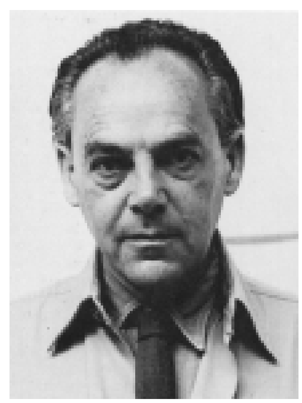


Figure 71: Gyorgy Kepes.

The course was set, scientists and artists would take each other to a new level; and over the following years, they were highly successful in doing so with contributions from prominent figures such as Takis, and Otto Piene who later became the Center's director.

11 Davis, Douglas, *Art and the Future*, Praeger Publishers, New York, 1973, p.116.

Although CAVS still exists and continues to produce provocative work, the spotlight on the MIT campus has shifted to the site of a highly visible research facility, the Media Lab, where a unique and innovative funding strategy has empowered researchers with an uncommon range of freedom. Under this arrangement, private sponsors of the lab are organized into consortia, each contributing a fixed amount of capital. With few exceptions, sponsors do not participate directly in any research happening in the lab, but in exchange they gain full and exclusive access to all research and all technology developed in the lab.

Although this arrangement was conceived primarily to bestow maximum academic freedom upon faculty and researchers and thus provide the most fertile environment possible for performing scientific research, this wide-ranging freedom has had the beneficial effect of creating a prosperous setting for artists. Although few research groups withing the Media Lab set as their mandate to create art, the free-spirited attitude that prevails inevitably leads to healthy overlap much in the spirit of CAVS, thus the shift in focus form the latter to the former.

The Aesthetics and Computation Group stands out as an exception within the Media Lab as it is one of the few groups with a primarily artistic mandate. The group works under the direction of John Maeda, an established graphic designer, and a pioneer in computational graphic design. The mandate of the group, unequivocally, is to raise standard of aesthetic quality in the field of computer generated design; a field which is suffering from an over-abundance of ill-conceived tools and ill-trained practitioners. Members of this group typically have combined background in computation and the arts (graphic design, architecture, fine arts) and are encouraged to express the maximum degree of individuality while producing complex, highly computational work. The group is a distinguished model of production where no gap exists between artistic and scientific endeavor.

MIT is by no means unique in sponsoring a collaboration between art and technology. Most technology institutes do so to some extent. Another exemplary case is the University of Illinois at Urbana-Champaign and its state-of-the-art National Center for Supercomputing Applications (NCSA). Their advanced visualization systems, such as the CAVE, have been put to use by artists from the outset. A strong example is set by Donna Cox, a jointly appointed professor at the School of Art and Design and at NCSA. Cox, an established authority on scientific visualization, has been equally prolific in her artistic production using precisely the same technological facilities; a singular embodiment once again of the artist-scientist.

The art-science gap is not being bridged solely from the side of technology. During the early 1990's the Banff Center for the Arts in Canada held a program called *Virtual Environments* where a talented group of technologists and established artists (including Michael Naimark and Bill Seaman),were brought together with large quantities of hardware and software and proceeded to make a series of ground-breaking interactive art installations. Michael Naimark, a CAVS alumnus, and veteran of Atari and Apple multimedia laboratories describes it, "*The Banff Center for the Arts had the most remarkable program for art and technology I'd ever seen.*"[12]

Although the *Virtual Environments* program no longer exists at Banff, other institutions and programs are on the increase. In Ogaki City, Japan, journalist, academic and longtime patron of interactive media Itsuo Sakane founded the International Academy of Media Arts and Sciences. Its mandate in Prof. Sakane's precise words is *"to integrate information science and art in the future."*[13] It is remarkable and significant that an institution has been founded on and is committed to this mandate.

The example set by these programs and institutions should serve as a beacon of light for the innumerable art, architecture and design departments throughout the world that are languishing in isolation, longing to be current yet lacking the will or ability to do so. Prevailing *high-art* attitudes, where focus is maintained on the study and refinement of existing modes of practice and well-established media, have had an unfortunate streamlining effect, withering ties to other communities, scientific not least. For the contemporary art department, flexibility and collaboration between academic units must be revitalized lest they become institutions strictly for the study and not the creation of art.

It will not suffice however that the development and practice of an art-science fusion take place under the highly subsidized protection of academic institutions. As globalization pushes free market practices into all corners of civilization the art world becomes more and more dependent on direct corporate support for survival. This is not a trivial matter. In an era of downsizing and mega-mergers, support for the arts is substituted for the purchase of factories and cheap labor in the third world. In the spirit of Adam Smith, capitalism is not proposed as a vehicle for personal enrichment, but rather as the most efficient model to raise the standard and quality of life for all subjects. Smith himself lived a simple life

12 Naimark, Michael, *Art ("and" or "versus") Technology*, from *Art@Science*, Christa Sommerer & Laurent Mignonneau eds., Springer Verlag, Vienna, 1998, p.128.

13 Sakane, Itsuo, *The Historical Background of Science Art and Its Potential Future*, from *Art@Science*, Christa Sommerer & Laurent Mignonneau eds., Springer Verlag, Vienna, 1998, p.229.

and gave most his wealth to charity. Since then the quintessential element of social responsibility has receded in the face of the soulless capitalist juggernaut. Smith, now rolling over in his grave, could scarcely have anticipated the rampage undertaken by contemporary corporate culture. Yet, who would agree to exist in a world without art, the very embodiment of culture. A re-evaluation of corporate responsible with respect to arts and culture is in order. How can it be possible that a corporation employing 100,000 people or more not have a single artist on its payroll? Yet this is not uncommon. Now imagine living in a town of 100,000 people, none of which are artists!

Yet there is reason for optimism. The Xerox Palo Alto Research Center (PARC), a world class facility having created universal standards in user interface design and network protocols among many other things, has made the employment of artists at its facility an integral part of its mandate from the outset. There, artists and research scientists work in tandem, much in the spirit of Kepes, providing a continual counterpoint to each other's unique outlook, and ultimately taking each other to a higher level of performance.

Another shining example can be found in the case of the Interval Research Corporation(also in Palo Alto), a research facility founded and owned by Paul Allen, one of the co-founders of Microsoft. Following in the mold set by Xerox PARC, Interval has film makers, designers, musicians, cognitive psychologists, artists, engineers and software developers on staff. Interval's mandate is to identify and develop concepts and technologies that are beyond the next iteration of production. It does so through its own research and development and by maintaining a solid network of ties with academic institutions working in a similar vein. Where most corporations work on a 3-5 year implementation schedule, Interval looks five, ten, or fifteen years down the road. Why they would consider the contribution of artists to be integral to this task should come as a surprise to nobody.

Elsewhere, private corporations heed the call through the creation of institutions fully dedicated to the cause. In Japan for instance, Nippon Telephone and Telegraph, one of the world's largest telecommunication firms created the *InterCommunication Center* (ICC) in 1992. Its mandate reads as follows, *"ICC aims to promote dialogue between science, technology, art and culture and to envision a society for the future that is rich in imagination and creativity... Contemporary society needs to break free from the dichotomy of technology and art and bring together diverse concerns, transcending the barriers of cultures and systems."* [14]

14 Intercommunication Center Web site, *About ICC*, www.ntticc.org.

That such mandates are becoming increasingly common certainly gives reason for hope. If these are the contemporary role models for the benefactors of the coincident practice of art and technology, who then, are the role models for the practice itself? Already we have discussed Rauschenberg, Krueger, Viola, Campbell and Cox. But in this field defined by Moholy-Nagy and Kepes, few individuals have embodied the mastery of art and science to the extent of *Artificial Evolution* designer Karl Sims. Possessing an education in biology and in Media Arts and Sciences, Sims created an awe-inspiring body of work during his tenure as research scientist and artist-in-residence at super-computer maker Thinking Machines during the early 1990’s. There, Sims applied his fascination with Darwin and the principles of evolution, in conjunction with the power of the world’s largest massively-parallel computer, to simulate evolution and create artificial life forms. Through a combination of programmed genetic algorithms and a user-guided natural selection process, he simulated the evolution of creatures through a great number of generations resulting in a development of species that mimics that which we observe in the actual biosphere. The resulting creatures, rendered in three-dimensional space, with their quirky unexpected, and virtually inexplicable behavior are without a doubt the most vivid representation of the complex and abstract concept of evolution ever produced. In looking at Sims’ work we cannot help but recall his renaissance predecessors, and their efforts to reveal the divine form of nature through artistic endeavor. The high standards set by Sims, a recent recipient of the prestigious MacArthur grant, serve as a benchmark for anyone operating in this field.

As the examples multiply, the framework set forth by Moholy-Nagy and Kepes takes root in the fabric of society. Innumerable festivals, exhibitions and symposia around the world such as Ars Electronica, SIGGRAPH(Special Interest Group on Computer Graphics , and ISEA (International Symposium on Electronic Art) grow in significance, giving further credence to this movement. Globalization and mass communication effectively diminish social and political barriers that have hindered the pursuit of art and science. The resulting arena for human expression will be unprecedentedly democratic.

7 Conclusion

From the outset, this thesis had the dual objective of pursuing technological research in a specific area, high-bandwidth I/O on conventional computers, while evaluating the feasibility of doing so within an artistic context.

This task was accomplished through the study and analysis of the relationship between art and science/technology over the history of civilization where specific examples were identified illustrating the various modes of communication that have specific relevance to contemporary activities. Throughout, the treatise of numerous authors, scientists and philosophers were reflected upon in an effort to define the artist/scientist over history. This knowledge served as inspiration in the design and completion of prototypes and installations, and to create a mind set for future work.

Thus, we conclude that waving one's arms in a controlled area while interacting with light-based illusions is really nothing new. We created work done in neither or both the name of art and science and have not found this to be contradictory. We developed new technologies with market potential, and we have taken part in international exhibitions by presenting these technologies as art. In the process we raised the ghosts of Borges and Adam Smith to invoke both optimism and pessimism with regards to the current state of affairs. In the end we established that the perceived dichotomy of art and science dissolves under a broader lens. The future, as always, is promising.

> *A man who cultivates his garden, as Voltaire wished.*
> *He who is grateful for the existence of music.*
> *He who takes a pleasure in tracing an etymology.*
> *Two workmen playing, in a cafe in the South, a silent game of chess.*
> *The potter, contemplating a color and a form.*
> *The typographer who sets this page well, though it may not please him.*
> *A woman and a man, who read the last tercets of a certain canto.*
> *He who strokes a sleeping animal.*
> *He who justifies, or wishes to, a wrong done him.*
> *He who is grateful for the existence of Stevenson.*
> *He who prefers others to be right.*
> *These people, unaware, are saving the world.*[15]
> *Borges*

15 Borges, Jorges Luis, *A Personal Anthology*, Grove Press, New York, 1967, p. 97.

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