Holographic Stereograms:
Three Dimensional Artwork from Computer Graphics

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Abstract

The goal of this thesis is to explore methods for the creation of computer generated holographic stereograms, concentrating on their potential as artwork. There is a need for strong images in this relatively unexplored medium, in which computer graphics and holography complement each other. The primary emphasis is on strong design incorporating graphical elements that enhance the three dimensionality of the image. The images must address aesthetic and perceptual issues in order to succeed. These explorations will be complemented by descriptions of the systems used. This includes software, hardware, and the holographic process.

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Chapter 1

Objectives

1.1 Holographic Image Development

The goals of this thesis have been to explain the method and explore the medium of computer generated holography. It is a powerful imaging tool, only in its infancy. The applications will span all fields; the subject of this thesis is the creation of artistic images.

Creative computer-generated stereograms depict a scene composed utilizing computer graphics, a synthetic world generated for three dimensional representation. Design to enhance this medium has been my primary personal concern. Previous work in computer stereograms has often been produced in conjunction with technical research, with little opportunity to address aesthetic issues. This is not unusual in an infant field, however the perceived quality is mutually dependent on technicians and artists. This thesis research has concentrated on the elements necessary for successful work in three dimensional imagery, including the constraints inherent in
holographic composition. Explorations into aesthetic and spatial perception and incorporation of both two dimensional and three dimensional computer graphics into the images are discussed in detail.

1.2 System Description

The computer graphics were composited using a variety of systems: for painting, designing the 3d objects, rendering the objects, and finally outputting the graphics onto 35mm film. This film was then transferred into a hologram via a two step, holographic lab set-up. The final holograms are white light viewable. A full description of the systems utilized follows along with observations on future additions that would enable freer artistic expression in this highly structured medium.
Chapter 2

Background Information

2.1 Brief overview of holography

2.1.1 History

Laser viewable

The history and theory of holography is being increasingly well documented, which makes it unnecessary to give more than a brief overview to understand the process utilized in the production of the stereograms[4][5]. Holography was conceived of by Dennis Gabor in 1948, who won a Nobel Prize in 1971 for his discovery. The invention of the laser in 1960 enabled Emmet Leith and Juris Upatnieks’ realization of the first “display” holograms. These early holograms had strict viewing and production conditions with dim images. Limited to precision lab work and small stable objects for the images, they were viewable with laser light shining through the film only at specified angles.

Subsequent developments in laser viewable holography lessened some
earlier restrictions. The disadvantages of expense and the inconvenience due to the need of a laser for display is counterbalanced by the experience of depth and detail in state of the art laser viewable work. A coherent light source such as a mercury arc lamp can also be used, but the extreme high resolution and depth is lost. An adjunct application utilizes pulsed lasers that enable exposures fast enough to capture portraits; unfortunately, high expense has deterred their wider usage.

**White light viewable holograms**

With the introduction of white light viewable holograms, the medium began to expand. However the necessity of working in a vibration free laboratory with precision optics and laser light for the creation of holograms has remained.

White light holography can be delineated into two basic formats: reflection and transmission. In reflection holography, introduced in 1962 by Yu. N. Denisyuk, the light reflects off the hologram’s surface. Reflection work is traditionally monochrome with the color dependent on the laser used. Recently, multicolor or “pseudocolor” effects have been incorporated, although they are still in the formative stages regarding color control. This process requires a separate exposure for each color after chemically treating the emulsion.

There have been other reflection techniques utilizing materials besides conventional silver-halide emulsions. These include dichromated gelatin, a material widely used to produce bright, but shallow holograms, usually in gold or silver colors. Photo-polymer, which is still in the research stage, is
effective but also very limited in depth.

White light transmission holography, invented in 1968 by Stephen A. Benton, entails viewing via light shining through the holographic plate \[8\]. The process takes advantage of the eye's horizontal placement and eliminates vertical parallax, the ability to look over objects. This has proven to be a very weak depth cue and is not usually missed in the holographic image. By decreasing the amount of information in the hologram, the need for a coherent light source was eliminated. It is a two step lab process, first a holographic master plate is made. For the white light copy, the master is masked off with only a slit of information projected onto the transfer.

For distortion free viewing there is usually a determined correct viewing position. The process has also been labeled "rainbow holography" due to the spectrum produced in viewing. The image appears monochrome but in different colors depending on height or distance of the viewer. Color mixing is possible with multiple exposures that position the spectrum in different places with each exposure.

Embossed holograms, widely seen due to their placement on credit cards and magazine covers, consist of the surface relief of a rainbow hologram pressed into foil to enable reflectivity. Thus far the images are limited in depth, even more then rainbow holograms.

2.1.2 Holographic stereograms

Holographic stereograms can utilize both of the above techniques, but this paper will concentrate on white light transmission format \[7\][6]. In
essence a combination of photography and holography, it has brought holography out of the confines of the laboratory. It is based on the principles of stereo photography, in which each eye receives a slightly different view of a scene and the brain fuses these views to see a three dimensional image. For holography, closely spaced perspective views are recorded on film, and then transformed into a hologram. The resolution and depth of focus is limited to the quality of the film taken, which can be recorded with a camera on a track for portraits or outdoor scenes, or recorded from views generated on the computer.

The first phase of research studied full parallax images. Research began in 1966 by Robert Pole[32]. In 1967 he proposed a two-step method using a fly’s eye lens backed with photographic film for recording the scene, then converting it into a hologram by projecting the pseudoscopic image back through the lens onto holographic film. This gave a grid of perspective views, covering the image area both horizontally and vertically.

A modification by J.T. McCrickerd and Nicholas George in 1968 involved taking sequential photographs of a scene through a pinhole with a large convex lens placed between the pinhole and the film. The transfer process placed holographic film behind the pinhole, retracing all the points [23]. Due to the large number of images needed, registration problems, equipment problems, and complexity of the lab work, these systems had little production beyond research. There have been other investigations into full parallax, but it is considered still as a future possibility.

The second phase of research eliminated vertical parallax, freeing the
process from the many constraints inherent in full parallax. Very influential in the development of stereograms was Dominick DeBitetto's research, forming the core for future work[12]. In 1969 he introduced usage of a horizontal sequence of photographs, instead of a grid. As in the previous research described above, his output was laser transmission. After recording an outdoor sequence the hologram was made by projecting each film frame through a vertical slit onto holographic film. For each exposure the slit was moved across the plate, all other areas of the plate were masked out. The slit width was chosen to be 3mm, approximating the normal eye's pupil size. The holograms width was larger than the interocular distance (6.5 mm) so that the viewer could comprehend the three dimensionality. Although limiting parallax, the image quality was maintained. Other research in 1970 by Redman and Wolton resulted in white light viewable images, but with very limited brightness.

In 1973 Lloyd Cross produced the Multiplex(TM) hologram, providing a breakthrough into mass production and the commercial marketplace. The holographic film, containing over a thousand perspective views, is wrapped around a cylinder, with the image suspended in the center. Lit with a white light below, the cylinder rotates giving the stationary observer a 360 degree view of a three dimensional scene. Many images were recorded on movie film with the subject on a rotating turntable. The process is one-step: each frame of movie film is projected through a large cylindrical lens, compressed into a slit and recorded onto holographic film with a coherent reference beam. Proximity copies were easily made, which aided wide distribution. One feature of Multiplex holograms was the addition of motion,
often blurred, but still effective. However there are problems with distortion, limited resolution, and lower brightness due to image area overlap.

Further research in white light stereograms has concentrated on presenting an image in truer color that is removed from the confines of the cylinder. The first stage has been to make achromatic, or black and white images. Different colors have different wavelengths which focus in different spatial locations. In achromats the spectral smear is mixed to form a black and white image. A two-step process was introduced in 1970 by King, Noll and Berry using computer generated images, in which the image was in black and white though of limited depth[22].

In 1979 William Molteni and Benton independently developed systems for producing flat, black and white stereograms of outdoor subjects[26]. Benton’s research has included much work in black and white, including stereograms. The process involves tipping the master hologram to what he calls the “achromatic angle”, enabling better color mixing in all directions in the transfer. This results in increased depth and stronger black and white images.

2.1.3 Color in holography

The quest for color images in holography has been part of the research from the beginning. Color mixing has been achieved with varying success using a variety of methods[3]. Most involve using multiple lasers of different wavelengths, for multiple masters produced with similar recording geometries. Still confined to laboratories, there are numerous technical problems
besides expense.

The research described above is geared towards natural color. Pseudocolor, which does not reproduce true color, can be done with a single wavelength. Reflection pseudocolor was mentioned earlier, and further details are not necessary for this paper. Transmission pseudocolor can be achieved by multiple exposures, changing the reference beam angle for each exposure. The colors shift depending on the viewer’s vertical orientation. However the combinations of color values remain correct.

Work in color holographic stereograms was documented by Lloyd Huff and William Molteni[18][27]. Huff concentrated on methods to generate colored Multiplex holograms. Molteni worked on making flat stereograms in color. Using color movie footage of an outdoor scene, filmed for holographic transfer, Molteni made three color separations onto black and white film. Then three holographic master stereograms were made, finally transferred into a white light viewable holographic stereogram. Chromatic and spherical aberrations compound the problem of registration which is crucial in this process. These and other optical problems limit the depth to only a few centimeters and there is a restricted viewing zone. However, further research promises to extend these limits.

2.1.4 Computer generated holography

Research in computer generated holography has taken two directions. The method in which the computer is utilized to calculate the fundamental diffraction capability of a hologram will not be discussed here. It is
computer intensive, and has had limited success. Using the computer to generate perspective views of a scene for incorporation into holographic stereograms is the approach relevant to this discussion. The views are output sequentially to 35mm slide film, with the computer generating each side to side view, akin to a movie camera on a track.

The first work was done in 1969 by King, Noll and Berry [22]. They used a plotter to draw different views onto microfilm of a computer stored three dimensional object. Their image eliminated vertical parallax, and was photographed similarly to the method described previously.

Computer graphics imagery has been utilized in various forms. In Multiplex holograms the images have ranged from molecules to data plots. They often incorporate motion; for example illustrating molecules changing form, or data plots growing. While the movement is an effective image addition, the inherent distortion in Multiplexes inhibit accurate data representation. Advances in computer graphics since 1976 have resulted in more realistic rendering techniques which carried over into more sophisticated holographic images.

There has been research into computer use for correcting distortions in Multiplexes. The computer has also been used for image processing, both with real and synthesized images. Current research at MIT has focused on using the computer for predistorting and manipulating computer graphics data. This is in conjunction with advanced laboratory processes and display formats, showing complex object data generated from various sources such as CAD-CAM systems and medical data.

Other work at MIT and Polaroid has concentrated on incorporating
computer graphics into flat holograms. These involve generating perspective views using combinations of computer systems. The holograms have ranged from small size black and white stereograms to large scale color renditions. This process will be described in detail in reference to the holograms produced in the thesis. Worth mentioning is a system developed by William Molteni[28]. It is home-computer based, and in addition to generating the multiple perspective views, enables three dimensional pre-visualization of the image in the design stage. The image is drawn using a digitizing tablet to specify the horizontal and vertical information and a joystick to specify the corresponding depth location. Included is a feature which generates two views, or a stereopair, enabling the user to see an image in three dimensions prior to shooting the hologram.

2.2 Computer graphics overview

Computer graphics is a vast field, continually expanding in scope. Graphics systems of increasing sophistication are becoming available, allowing less constraints on the user and greater freedom for design. Areas relevant to work in holographic imaging will be covered, further details can be found in texts and articles [13][33].

Raster graphics systems predominate. In these the image is broken up into a discrete array of pixels, and at which every screen point, or pixel can be independently accessed. The number of colors varies; for example on a professional system 256 are available at any one time from a total of 16 million, while a home computer often offers 16 from a total of 64.
Computer graphics terminology has developed distinctions between two and three dimensional images. Two dimensional graphics are confined to flat images, such as those created on a paint system. They can contain many complex functions for image manipulation in addition to software that approaches traditional paint and graphic arts materials in computer applications. Three dimensional graphics have the ability to generate objects and scenes in x, y, and z space. Views of an object can be generated from a myriad of viewpoints. The scene can be rotated in all directions, scaled up or down, and positioned or translated into different areas of the screen.

Objects are stored as mathematical descriptions in the computer. The object description is obtained from a variety of methods from which the graphics system is programmed to translate into usable data. These can include typing in the numbers, or drawing out the object with either a mouse or digitizing pen. Modeling or rendering techniques are utilized for drawing out objects, ranging from smooth shading to polygonal surfaces to wireframe outlines. Because they can be rendered quickly, wireframe outlines are often used as a previsualization tool, especially in animation.

The goal of realism in computer graphics has fueled much research. “State of the art” has meant lighting, shading, and other rendering techniques that strive to mimic reality. Recent work has concentrated on capturing reflections with ray tracing, building complex environments with fractals, and building animation systems that can infer movement from limited high level information, such as scripts [21].
Chapter 3

Designing for Three Dimensional Space

3.1 Depth Cues

Depth cues are important factors for consideration in reference to three dimensional vision and composition [20]. Hochberg describes depth cues as "the patterns that are likely to occur in the picture plane and in the proximal stimulation at the eye when objects are viewed from different distances. Thus, each cue, by definition, is a two-dimensional picture of a three-dimensional arrangement. Therefore each cue must be ambiguous in the sense that the same retinal image could be produced either by a two-dimensional pattern or by some three-dimensional arrangement, and any theory that bases our perception of space on these depth cues must consider space-perception itself to be equally ambiguous" [17]. In addition, when the mind is presented with confusing elements, it reaches back to past visual experience and attempts to organize those elements into familiar ones.
Depth cues are commonly categorized as binocular or monocular. Binocular cues, based on both eye’s coordinated interaction, include convergence and stereo vision, and concentrate more on the spatial orientation of the human visual system. The visual system utilizes selective focus; distance can be perceived as amount of blur. Convergence is the triangulation of the eyes relative to the distance of the object. Stereo vision results in the fusion of each eye’s view into a three dimensional image.

Monocular cues include size, overlap, aerial and linear perspective, accommodation, motion, elevation, color, and light and shadow. Based on a single eye’s vision, these have a large impact on three dimensional perception.

Overlap is one of the most powerful depth cues, given two objects the eye assumes the unobstructed one to be closer. Size constancy is also strong, as people have a constant memory of size; larger in front and smaller in back. The combination of similarly shaped overlapped objects, with the size decreasing, shows great depth. Additionally, excessive crowding of elements in a scene enlarge the space. Providing a similar impression are textures; the eye is drawn to their detail and regularity of shape. Their complexity is distinguished in the foreground, but definition is lost as depth increases.

Perspective is categorized as linear or aerial. Linear relates to image size, reconstructing a view based on receding lines. “Linear perspective defines the size, shape and disposition of the objects as drawn in the picture, with their foreshortening and the apparent overlapping of some near objects upon far objects, for one eye in a given position - and for this position only”[31]. Various methods using different geometries have been utilized,
combining one or more vanishing points to which lines from objects can be traced to. Aerial focuses on atmospheric haze, in which the loss of detail infers object distance. Commonly used by painters, the technique consists of adding unsaturated blues and less definition in proportion to distance [34].

Accommodation is the degree of focusing of the eye. However, after six meters the focus stays the same regardless of the distance. Although it is based on a single eye’s vision, it is mostly effective in combination with other binocular cues.

Color is a subtler depth cue. By increasing the amount of a color, distance is reduced, and consequently it often seems closer. Different color combinations result in changes in depth perception. It has been noted that on a black background, next to a neutral gray, yellow and white are viewed as closest, then red, then green with blue the farthest away. Warm, or red, colors advance and cold, or blue, colors recede. Given two objects of the same size, the lighter will look larger. In many cases luminance is a more effective depth indicator than color saturation [1].

Objects with opaque surfaces or hard edges aid in depth determination, with light reacting to difference surfaces, either by reflectance or absorption. Light and shadow gradations provide depth cues, with light usually perceived as overhead. Shading defines shapes, adding a solidity of form. Additionally light source direction is a known contributor to optical illusions; reversal of shadows can lead to depth reversal.

Motion in conjunction with depth perception assumes either a stationary observer of a moving scene or a moving observer of a stationary scene.
In moving past a scene, the front elements are displaced more dramati-
cally, then the distant elements. There must be something moving in front
or behind another object in order to perceive depth. Cinerama, a wide-
screen system only briefly in existence, gave viewers a feeling of true three
dimensional space, partially due to the inclusion of images in the viewers
peripheral vision, but also due to camera motion.

3.2 Related art historical issues

Depth representation and spatial perception has been a predominant
concern in paintings, drawings, photography and cinema. Viewing and
understanding the content of flat images has always been in conjunction
with the conditioning of the observer [16]. Starting with cave paintings,
cultures have developed styles that would have proved confusing to previous
ones.

Paintings in particular have been analyzed as to their depth portrayal.
Pirenne puts forth that viewed with one eye, through its frame, "assuming
the eye to be at the center of projection ... the flatness of the picture is
no longer evident, and the picture surface is no longer seen. So perspec-
tive, both linear and aerial, colour, light and shade, the factors specific
to pictorial representation, come into full play. The complex flux of light
received from the picture by the one eye used is similar to that which it
would receive from the scene represented. Accordingly the picture appears
as a scene in three dimensions"[31].

Flatness in a painting is more apparent when moving towards it. A
large painting, viewed at a distance, seems to have more realistic depth. In addition, paintings that contain distant views seem realistic due to the limits of stereo vision, as after a certain distance both eyes see virtually the same view. Although usually painted from a specific viewpoint, observing the painting from a slightly different angle does not present a distorted image if the position and shape of the picture surface is seen. In this case the mind compensates for the incorrect view.

The painterly representation is an interpretation of the real world, not an exact duplicate. "What a painter inquires into is not the nature of the physical world but the nature of our reactions to it. He is not concerned with causes but with the mechanisms of certain effects. His is a psychological problem - that of conjuring up a convincing image despite the fact that not one individual shade corresponds to what we call 'reality'. In order to understand this puzzle - as far as we can claim to understand it as yet - science had to explore the capacity of our minds to register relationships rather than individual elements"[14].

Monocular cues have been utilized in artwork throughout the ages, especially evident in the use of linear and aerial perspective, size gradient, and overlap. Overlap and size are regularly used in paintings; an example are the receding columns in Renaissance painting which aid in defining the space. Architectural elements also enlarge the feeling of depth, allowing the ability to look around and through structures. Placement of objects higher in the painting makes them seem farther away.

Light, color and shadow are essential elements in spatial representation. The use of light to define space is evident in all representational paint-
ing, and especially dramatic in the Dutch painters Rembrant and Vermeer. Two centuries later the impressionists based their work on the importance of light, working outdoors to capture its essence and forming new color theories for more realistic reproduction.

Oriental art developed independently from western art. Chinese landscapes were not concerned with the rules of perspective. They contain bird's eye views, with no specific viewpoint. The viewer travels through the landscape, stopping at familiar mountain tops and cottages, instead of being directed to a singular perspective view. Due to the inadvertent use of size constancy and inclusion of recognizable elements, the viewer did not experience spatial distortion. Japanese woodblocks have no spatial depth, shadows or aerial perspective, sometimes including different horizons for foreground and background.

Many disciplines have examples of work produced specifically to enable the viewer's experience of depth. Michelangelo's David, in order to be seen as anatomically correct from floor level is proportioned accordingly, with the head larger than normal. Stage sets are always designed with illusion of space in mind. There are numerous wall paintings in this category, the most cited is the painted ceiling by Andrea Pozzo in the church of St. Ignazio in Rome. This gives very strong depth impression when seen from a singular vantage point. However from other viewing areas there is image distortion.

Twentieth century art has moved beyond traditional representational concerns. The Cubist's were interested in showing different aspects of an object instead of a singular view. They sometimes referred to it as the fourth dimension. Abstraction concentrated on emphasizing the picture
Photography and cinema have played an enormous role in changing the way space is perceived. Cinema especially has contributed to what Dore Ashton calls the "dissolution of fixed perspective" [2]. Early audiences were shocked to see the discontinuity of cinematic portrayal of what was otherwise familiar scenery. This included cameras tracking scenes, quick cutting between shots, moving from close-up to long shot, or changing between camera angles. Photographic distortions of space by using unusual angles and lenses have also contributed to changes in spatial perception. However since photographs usually present central perspective, distortion in viewing is not experienced.

The element of change and adaptation will continue to be an important component of visual representation. "When the cinema introduced 3D, the distance between expectation and experience was such that many enjoyed the thrill of a perfect illusion. But the illusion wears off once the expectation is stepped up; we take it for granted and want more" [14].

3.3 Aesthetic and perceptual issues in holographic composition

The issue of design for three dimensional space obviously must be addressed in holographic compositions. Previous to holography numerous methods of three dimensional display were evident. The description of stereo vision dates back to Euclid, who wrote that the left and right eyes
see different views which are merged to see depth.

The invention of the stereoscope by Charles Wheatstone in 1838, subsequently improved on by Brewster and Holmes, presented images to each eye that were fused by the brain to form a three dimensional image. The stereoscope became extremely popular, due to the parallel development of photography. Other three dimensional imaging methods have been introduced since, including viewmaster slides, three dimensional movies, and lenticular postcards[29]. Most of these were used for entertainment rather than aesthetic purposes. The compositional concerns usually did not go beyond the practical ones of presenting a three dimensional image without distortion or viewer headaches.

Artists have been using these mediums although in mostly isolated cases. The challenges of designing for three dimensional space include image placement, minification and maxification besides traditional design concerns. Pirenne states “stereoscopic pictures … do give a 3D impression, but not a complete illusion: indeed, the almost perfect impression of relief given by the stereoscope tends to emphasize, by contrast, the limitations of the photographic representation in other respects”[31]. Many of the systems do not have the viewing freedom of holography, being limited to two views, or confined to viewing devices. There are exceptions, such as certain lenticulars, which are known to produce exciting images, but in limited circulation.

Holography’s emphasis can be described as sculptural; the hologram is focusing its image into different places in space. Elements can be projected out of the frame, or recede far into it. Particularly effective is the use of
planar images pushing through the space, adding definition.

Motion parallax is an important component in appreciating holographic space. By moving in front of the hologram the observer sees its elements moving in front of or behind each other, depending on their spatial position. This kinetic and interactive quality of holography, can never be created in two dimensional work. In addition, the traditional use of overlap, which in two dimensional work implies the third dimension, has been expanded to include the third dimension.

Designing for three dimensional space has different requirements. Compositionally, what would be successful in two dimensions, can be uneventful or even unworkable in three. Often, simplicity is most effective. Some of the strongest work in holography has contained only a few elements purposefully positioned in a black void. The many forms of holography present numerous options for imagery. Artists sometimes employ everyday objects in holograms, but with the goal to relay more than just a direct representation. Often the artist is commenting on holographic space, the fact that the hologram consists of focused light, forming a seemingly solid object. Mentioned below are different artists who powerfully explore the nature of holographic composition. It is a sampling chosen to illustrate issues I feel important in successful holographic work, rather than an overview of holographic artists.

Realistic still life setups were transformed in Margaret Benyon’s early work. She wrote “initially I was concerned to use only those aspects that were exclusive to holography, introducing people to unfamiliar notions about space with time reversed imagery or double-exposures in which
solids seem to share the same space, or non-holograms, which play havoc with received notions of surface, volume, part, and whole” [9]. She experimented with the spatially reversed image, or pseudoscopic, stating “with holography it is possible to record things invisible to the naked eye, or turn space ‘inside-out’ ”[10] Other images further explored holography’s process and unique capabilities. By presenting a hologram in pieces, each containing a different viewpoint, the ability of holography to capture the “whole image” was illustrated.

Setsuko Ishii’s work involves combining real objects with their holographic image in installations. One piece consists of plastic hoses whose holographic images extend off the plate into their real life counterparts. She states “this medium can create a new situation which we have not been able to experience so far. It can result in a discord between visual and tactile senses. A three dimensional image which visually seems to be an existent object is actually not an object which we can touch. We cannot apply our traditional recognition process beginning with sight to such images. We are forced to reconsider how to recognize the existence of objects ... Thus technology expands art expression methods and presents new subjects to us”[25].

Much holographic work has been non-representational, of which some of the finest have been created by Rudy Berkhout. He has concentrated on the properties of light and it’s inherent sculptural qualities. The images contain abstract objects, many exhibiting kinetic features. Shapes tumble and reform in conjunction with the viewers’ movements. Color is used selectively; by isolating smaller objects on a black background the problems
of unintentional color blending are alleviated. There is a purity of the image, resulting in many of the strongest statements in holography.

The concerns of purism, and retaining holography's distinct identity are important recurring themes. As stated earlier artists have taken many avenues to achieve this. The treatment of the surface is another such exploration. An example is in Doug Tyler's pieces, which collage flat tape with simple abstract holograms. "I like the movements of the planes but I also like the sense of dichotomy between the flatness of the film and the planes... forces you to make a comparison and deal with the confrontation between the physical thing (the lines) and the non-physical things created totally with light"[30].

Computer graphics opens up other possibilities of expression. The ability to generate a completely graphical image, either representational or abstract can be quite powerful. It is a personal interest to pursue artistic images in this medium. Experimentation in design has only begun, and there are many options to introduce creative, previously unexistent images.

The inclusion of monocular depth cues in holographic composition can be used to increase the illusion of depth, playing on the assumptions of vision. In conjunction with three dimensional objects, the use of color cues, size consistency, and overlap can aid in enlarging the sensation of space. By introducing painterly elements the illusion of depth can be controlled. In this context, exaggeration is achieved using similar techniques that painters have used to express space on a canvas.

Besides methods that can be used to enhance dimensionality, there are many constraints unique to three dimensional compositions. Primary is the
awareness of the picture's boundaries. Images projecting out of the frame cannot intersect that frame. With intersection the unfortunate result is that the image is pulled back to where the frame is located in space, instead of retaining it's frontal position. Depth determination is also important, placing objects too far back in space or projecting out too far in front results in viewing problems and sometimes double images.

Certain elements can be spatially confusing when viewed in a two dimensional composition. When viewed binocularly the elements magically position in space. Primary are complex patterns and textures which give little clues as to spatial orientation. Also confusing until viewed in three dimensions are overlapping objects, in which their spatial position is not apparent.

3.4 Artists in holography

Artists became attracted to holography from early on, despite the numerous limitations in the beginning imposed by the need to have access to a lab, and the necessity of a coherent light source for display. Noticeable in the early years was the interest of a few well known artists, especially Salvador Dali and Bruce Nauman. Their work was produced in conjunction with established labs, freeing them from technical responsibilities. Bruce Nauman produced pulsed self-portraits as an adjunct to his work in performance. Dali's pieces ranged from stereograms to laser transmission holograms that he manipulated and painted on. These were exhibited in 1972 at the Knoedler gallery in New York. As early as 1970 Douglas Davis
mentioned holographic art in Newsweek.

In addition there emerged the first generation of holographers who approached the medium as valid for their personal artistic expression. Margaret Benyon personifies this approach as someone whose work, beginning with laser transmission pieces, has evolved along with the medium. In numerous articles she has analyzed the medium historically and in relation to her own work. Writing in Leonardo, “it seems that art writers and theoreticians have been largely unwilling to spend the time necessary for the assessment of holographic art on its own terms. In a similar way, not many holographers seem to take a close interest in other kinds of contemporary visual art. If holographic art is taken to be not merely a demonstration of design and manipulative skill but of originality, then artists could avoid mistakes similar to those that occurred in the early history of photography” [11].

The phenomenon of basement labs became a necessity for artists to pursue holography without the constraints of expensive equipment and limited access. This enabled experimentation, and evolution of personal styles. Strong work has emerged from individual artists, documented in holography texts and exhibition catalogs.

Holography has been presented in various environments. New York City’s Museum of Holography, founded in 1976 by Rosemary Jackson, was the first exhibition space dedicated to holography. Still open, it has provided a support system for holographers and encouraged the medium. The growth of galleries and museums devoted to holography worldwide has been in continual flux with varied display quality. The phenomenon of block-
buster shows of holography emerged for a brief time, bringing quantities of work to the public. Unfortunately, at the time of this writing holography's acceptance into the mainstream artworld has remained sparse.

3.5 Goals in my holographic work

My holograms consist of two and three dimensional computer graphics. The pieces attempt to expand the vocabulary of computer generated stereograms. To date most have been finely rendered three dimensional scenes. By including paintings that relay depth cues, I have begun to address the issue of painterly representation of three dimensions in a two dimensional space.

Three images are described below. The first piece, StillLife, consists of a paper bag floating on top of a table that is jutting out of the image plane. The background contains a row of thin italian trees and columns, a reference to the historic use of perspective in painting. The subject, a traditional still life, was chosen in contrast to the newness of holographic representation.

Zigzag contains three dimensional zigzags and frames floating in space. They are positioned in front of and behind two paintings. The paintings are abstractions which relate to the three dimensional objects. They show jagged lines on rectangles. In one, the rectangles are positioned on top of others, using different colors to give shadow effects that enlarge the space. The second painting is smaller, and only contains one rectangle. It is positioned in front of the other painting, complementing it and relating
to it. The three dimensional objects were rendered in various shades of gray in order to increase depth, with the lightest in front, the darkest in back. The open frames provide windows to look through to see different views of the objects behind. Both the frames and zigzags are contained in the paintings. The piece is random in feel, although compositionally quite structured.

*Bottlelandscape* has a background painting of a row of quickly painted bottles. It includes a small rectangular window looking out onto a mountain landscape which opens up the space. In front of the painting are various three dimensional bottles, consisting of two large ones in the front right and a grouping of four smaller ones on the other side. They are spatially positioned with the largest and brightest in front. The grouping of four bottles illustrate the difference of viewing in three dimensions, they present a confusing two dimensional view, but expand spatially in the hologram. The bottles obscure each other, but move in depth.

In these pieces design choices were modified according to the constraints of the systems used. However, the original concepts stayed strong. Image composition plays an important part, the elements have to interact with each other in space without conflicting. Each piece, although different in subject matter, had similar motivations: to be unique, explore the medium, and add to the illusion of depth. The elements in each composition refer to each other, connected in subject but in distinctly different spatial locations, providing the ability to look through and around.
Chapter 4

System Breakdown/Documentation

4.1 Computer Graphics

4.1.1 Overview

Numerous methods have been used in the Media Lab to generate holograms. There is no one compact package in existence. Instead there are various system components available. These are used in conjunction with each other, dependent on the imagery and format desired. Being primarily a research lab, the emphasis has been on component development instead of system building. Modifications and additions are continually made, refining and improving the procedures. The procedures used for the stereograms were chosen for their utility rather than elegance. Other methods have been used with success, although they are not appropriate for these specific applications. A few improvements, not completed in time to use will also be mentioned.

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4.1.2 Documentation

The first piece, *StillLife*, was generated using a graphics package written by John Lewis and modified for holographic output by Michael Teitel. Using a Perkin Elmer 3230 computer, it was written in PL1 on the Magic Six operating system developed at MIT. The graphics package is composed of different types of renderers, several of which were used to generate the hologram.

The bag and the table used “editslice”, in which vertical slices of an object are drawn on a digitizing tablet. These are then connected using “bnuts6”, which renders triangularly tiled objects. Different shading options are available. Predominantly used were those which shaded the tiling without fully smoothing the object. The trees and columns were drawn using “revolver”, which takes an outline of rotation as input producing a cylindrical object. The background mountains were generated taking a black and white painting done on a paint system written by Walter Bender. These were mapped onto the back plane using “billboard”, a function that maps two-dimensional images onto planes tilted in a variety of directions.

In order to render the whole scene, a program named “fish” was used. This provides a script which draws the complete animation. It contains information for camera movement and keystone correction. For stereograms the animation moves along the x axis, from the far left of a scene to the far right.

The frames were generated on the Ramtek frame buffer which was patched into a Dunn camera, which is pin-registered and holds academy
format 35mm motion picture film. It is computer controlled, and exposes
the frames generated by the script. The film used was 5247 color negative
stock.

The other holograms, Zigzag and Bottlelandscape, used a similar combi-
nation of systems. A paint program, developed at MIT’s Visible Language
Workshop by Tom Amari and Bob Sabiston, for use on the Hewlett Packard
Bobcat, was used for the creation of 8 bit color paintings. These were then
transferred to the Vax and color separated into 8 bit red, green and blue
components. Each separation was shipped to the Symbolics 3600(TM) Lisp
machine, combining to form the original painting, in 24 bit color.

The paintings were incorporated as texture maps into a graphics package
developed at Thinking Machines Corporation called the “TMC 3D Image
Toolkit”. The program is an interactive object editor and scene assembler.
Objects can be saved on disk independently, or in a world which contains
a combination of objects. The worlds store information necessary for re-
drawing the scene, including placement, lighting and color specifications.

Utilizing a window system and mouse, the functions are listed in a main
menu that when chosen display options either with submenus or on a line
printed at the screen’s bottom. Numerous shapes can be drawn, from basic
ones such as spheres and cubes to more complex objects. Operations are
available to draw different shapes, including “lathe”, similar to “revolver”
on magic six, and “prism” which takes as its inputs the outside and inside
borders of an object. Input into the number of polygons forming the object,
when relevant, is asked for.

Other components are translation, scaling, rotation, with a few different
methods to control object size and placement. There is a color editor, with sliders for color mixing that allow for fine tuning color choices. Diffuse and specular reflection can be determined for each object. Light sources can be placed, including adding extra lights if necessary. The ability to change viewing and shading parameters gives great flexibility in designing an image.

*Zigzag* used “prism” to model the zigzag and open frame shapes. Two paintings were texture mapped onto cubes, placed in different planes in space. The bottles in *Bottlelandscape* were rendered with “lathe” using a different number of polygons dependent on size, the smaller bottles requiring less. A texture map onto a cube was placed in the background. Shooting was also on the Dunn camera, enabled by controlling and rendering programs by Karl Sims.

### 4.2 Design Concerns

In designing stereograms it is necessary to determine a number of factors that are important in rendering the computer graphics and in printing the hologram. These include calculating the viewing distance, the angle of view, size of hologram, and the number of views. The angle of view is determined by the width of the hologram and the distance from the hologram to the viewing zone. The number of views is calculated by dividing the viewing zone width by the slit width, usually 3mm.

The stereograms produced for this thesis are fitting into a similar holographic laboratory setup. *StillLife* has around seventy perspective views,
the other two are composed of one hundred perspective views. The size of the final hologram is eight inches square, and the viewing distance is approximately 50 centimeters.

4.3 Holographic Imaging

The holographic printer is set up in a vibration free basement holography laboratory at the MIT Media Laboratory. It is equipped with a Newport Research steel holography table, and a variety of optics including mirrors and lenses. An argon laser emitting a green beam, wavelength 514 nanometers, is used.

The set up for printing the holograms is two step. First a master hologram is made containing all the perspective views. These are recorded as 3mm consecutive slits. The object beam has a complex path. From the beam splitter it goes through a spatial filter and lens before the movie footage. The illuminated image is then projected through a Nikon lens onto a Polocoat diffusing screen, and then through a slit onto the holographic plate. The reference beam is collimated, and baffles are placed between it and the plate to allow only a slit of light to reach the plate.

The slit stays stationary, while the plate moves upward for each consecutive exposure. This is done with a computer controlled Velmex stepping motor. It is programmed to move up after each exposure, allowing for settling time and the number of exposures. After exposing the plate is processed using the PAA processing technique and bromine bleach.

The second step is the transfer. This is much simpler, it only involves
one exposure. The master is illuminated with a collimated beam, projecting its image onto a transfer plate. The reference, shining onto the transfer plate is not collimated. Processing is as described above.
Chapter 5

Observations

5.1 System

5.1.1 Critique

The system used, as stated earlier was a hybrid of many components. There were many problems encountered due to lack of documentation, and the necessity of relying on a few different systems to produce image components. The goal of incorporating paintings into the holograms limited the options to the one system that includes texture mapping functions. However it turned out problematical due to unforeseen machine malfunctions.

The "TMC 3D Toolkit" greatly enhances the process of image design. Although there are subtleties of usage that rely on additional programming, its capabilities are still quite substantial. The ease of positioning objects in spaces, and ability to receive numerical information on their exact position, is important in holographic design.

The holographic printer presented no major problems, besides those
expected in debugging holography laboratory setups. Hopefully someday it will be a standard form of three dimensional hard copy.

5.1.2 Improvements

Many improvements can be made. The lack of documentation inhibits wider usage and experimentation by users other than those intimate with the workings of the machines and their specific programming language. There are numerous idiosyncrasies due to the nature of the research lab, and systems are often customized to the latest user’s needs. This results in a forced reliance on tracking down the individuals with the information. An obvious improvement would be to add documentation.

Ultimately a complete system for designing stereograms is desirable. This would compose of numerous options for image design and rendering, and ease of film recording. A system in development at the Media Lab will hopefully fill many of those needs.

Already implemented is a renderer written by Dave Chen and Brian Croll, appropriately titled “Rendermatic”. It renders scenes according to programs calling its functions, providing shading and lighting options. Unfortunately texture mapping hasn’t yet been incorporated. A data generation package, which will supply “Rendermatic” object data in the correct format is in the works. An object editor is also being written, which should ultimately be similar to the TMC graphics package.

Additions specifically for stereograms should be considered. These include programs which calculate the viewing and depth requirements, and
allow grayscale color separations for color holograms. Having a system accessible on the network of computers, instead of being dependent on a using a single machine with high usage should be a necessity. For the Media Lab, this means having numerous Bobcats for use as design stations, prior to rendering the final image on the Vax's Ramtek.

5.2 Holograms produced

5.2.1 Critique

As in all artwork, the technique restricted the freedom of choice. The original designs were tailored down to fit the computer graphics system used and the time constraints involved. Equipment problems also contributed to some redesigning. There are a few changes that would improve the image, which were not apparent until the graphics were recorded onto film. A few elements projecting out of the image should be repositioned because they move out of view in some of the final frames. Also the texture mapped paintings wrap around the cube, and in a few of the views begin to reveal the painted sides. However the holograms produced stayed true to the initial design concepts. The images successfully convey the concept of combining two dimensional computer graphic paintings with three dimensional computer graphics. They fill the holographic space without being overdemanding.

Unfortunately time did not allow the realization of more images. There are many other ideas that have to be stored away for future artwork.
5.2.2 Future possibilities

There are a myriad of enhancements in both process and image design. The addition of color would be the first step. Further explorations include incorporating paintings, both as textures and for expanding depth perception. Exaggerating the depth cues, both in paintings and with three dimensional elements is a key objective.

In terms of process, the use of tablet and pen, drawing in 3d space as if drawing out a sculpture would be a wonderful tool for composition.

The most important addition is that of the field growing to the point that holographic stereograms are easy to produce outside of a research lab, and become a common form of image reproduction.
Figure 5.1: *StillLife: middle view*
Figure 5.2: Zigzags: right view
Figure 5.3: Zigzags: middle view
Figure 5.4: Zigzags: left view
Figure 5.5: Bottlelandscape: right view
Figure 5.6: Bottlelandscape: middle view
Figure 5.7: Bottlelandscape: left view
Bibliography


