LAKE FOREST COLLEGE

Senior Thesis

A Brief Introduction to Display Holography: Curation of the Lake Forest College Holography Gallery

by

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May 1, 2018

The report of the investigation undertaken as a
Senior Thesis, to carry two courses of credit in
the Department of Physics and the Department of Art and Art History

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ABSTRACT

A hologram is a complex diffraction grating made by recording the interference pattern of two radiation fields on a light-sensitive surface. Holography is the study of this process. While holograms have been used for many purposes, I'll focus on holography's role in the art world, through the examination of Lake Forest College's hologram collection, and subsequent curation of the holography gallery.

Holograms are nearly absent in the art world today; there aren't frequent exhibitions in holography, or many holographic artists working publicly (perhaps for justifiable reasons). However, it seems that the aesthetically striking nature of holograms cannot be ignored in the art world, once presented. If holography were reintroduced to the art world (and perhaps the art world to the holographic community), conditions may be right for another "holographic renaissance," especially considering the changes in artists' and audiences' mindsets and expectations over the time that holography has lied somewhat dormant.

ACKNOWLEDGMENTS

NOT REQUIRED. 2-3 paragraphs, usually. Don’t forget to thank your committee members

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I. INTRODUCTION

The word "holography" was derived from the Greek word *olókliros*, which means "whole" or "entire picture."[1] Thus, "holography" implies the study of the entire picture. Dr. T. H. Jeong defined holography as "the recording of the interference pattern between two mutually coherent radiation fields on a two- or three-dimensional medium."[2] The result of this process is a complex diffraction grating called a hologram.[2] Holograms can be made of essentially any object, although rigid, reflective objects often work best.

Holograms are capable of presenting truly striking images with incredible depth and detail. Looking at a hologram is similar to looking through a window—you can move from side to side and see different views of the holographic object, and if part of the "window" is covered, you can still look through the uncovered portion to see all that's on the other side.[3] Through one of these holographic windows, you might see a vibrant, colorful object in breathtaking detail, sitting in a deep space which stretches beyond the frame or the bounds of the glass plate.

Holography experienced a sort of reawakening in the 1960's, at which point audiences realized the immense potential that holography holds. Its uses have included scientific research, data storage, radar, consumer goods, industry, and artistic expression.[4] Personally, as an artist, this last way is particularly interesting to me.

II. SCIENTIFIC THEORY

In order to understand the science of holography, we need to gain an understanding of at least the basics behaviors of electromagnetic waves. In particular, we'll aim to describe the interference of "two sources of continuous waves, emitting at the same constant frequency."[2] Since the two waves have the same frequency, they're mutually coherent. While the concepts we'll discuss can be applied to any coherent waves, we'll focus on their applications in optical holography.[2]

A hologram is the physical result of recording the pattern formed by the interference of laser light. Thus, to study the physical working of holography, we must "analyze the recording and reconstruction of the wavefronts of a three-dimensional object," as Jeong once stated.[2] There are multiple ways of conceiving of the relevant scientific ideas, but we'll consider the geometric model, a physical model to help holographers visualize what happens during their work in the laboratory. The geometric model is generally more accessible to the artist, non-scientist, beginner than, say, the Fourier model (a formal, mathematical description of holography, helpful to those with a background in science and mathematics).

A. Addition of Sinusoidal Waves

When considering electromagnetic wave interference, we can begin by thinking of a simple sinusoidal wave, as shown in Fig. 1. The highest point on this waveform is called a crest or peak, while the lowest point is called a trough. The vertical distance from the center of the wave to a peak or trough is called the amplitude of the wave. The horizontal distance from crest to crest (or from any arbitrary point, through a crest and trough, and then back to that same point) is one wavelength.

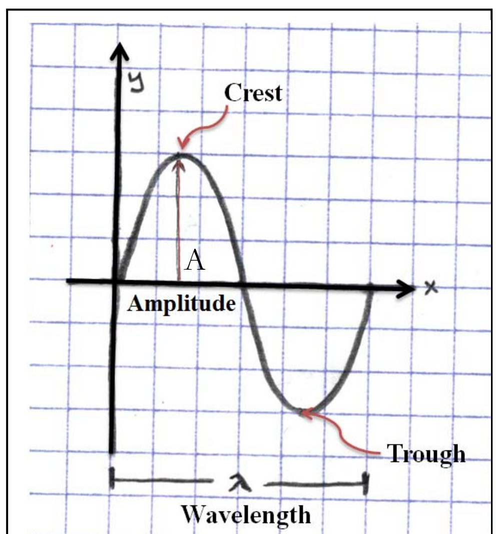

FIG. 1: Sinusoidal wave with amplitude A and wavelength λ

When more than one sinusoidal wave is present in some space, we can add the amplitudes of the waves to see how they interfere with one another. This interference can either be constructive or destructive. Constructive interference occurs when the amplitudes of the waves combine to form an amplitude larger than either of the two waves had initially. Fig. 2 shows a simple example of constructive interference in which the two waves being added have the same phase and frequency. Allowing the length of one blue square in Fig. 2 to be one unit, we can see that each initial wave has an amplitude of two units. The amplitudes add at every point along the horizontal axis, so the resulting wave is sinusoidal and has an amplitude of four units.

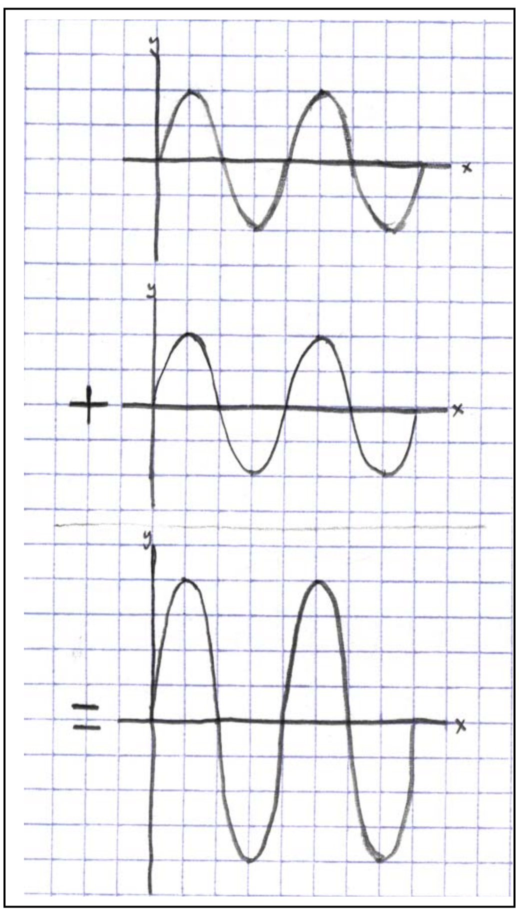

FIG. 2: Constructive interference of two sinusoidal waves with the same frequency and phase

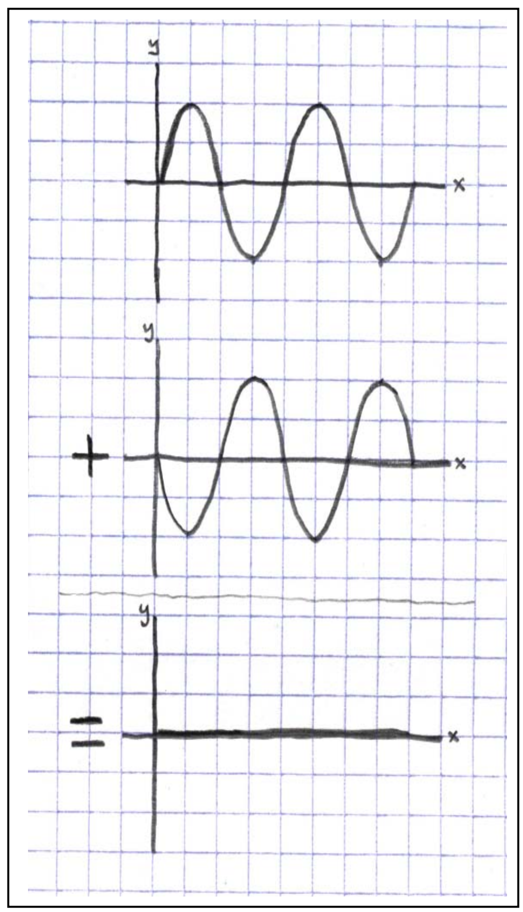

FIG. 3: Destructive interference of two sinusoidal waves with the same frequency, but 180 degrees out of phase

During destructive interference, on the other hand, the amplitudes differ in sign, and thereby result in a wave with an amplitude smaller than at least one of the initial amplitudes. An example of destructive interference is shown in Fig. 3. In this case, the initial waves still have the same frequency, but are 180 degrees out of phase with one another. As a result, they completely cancel each other out—the resulting amplitude is zero.

Thusfar, we've considered some of the simplest cases. Notably, white light and ambient light are generally made up of a multitude of waves with many different frequencies, and when the interfering waves have different frequencies, the resultant wave can be non-sinusoidal and fairly complex. However, holography requires coherent light, which means that the phase difference between the two waves must be constant.[2] This implies that, while the waves don't need to have the same phase, the interfering waves must have the same frequency and wavelength. We can get controlled, coherent light from lasers. So, theoretically, we don't need to worry about waves with different frequencies, and the resultant waves in our case remain relatively simple.

B. Geometric Model

The next step is to imagine waves of constant frequency being emitted radially outward from some source. A pictorial representation of this is given in Fig. 4. We can think of the light areas as crests and the dark areas as troughs. The distance between concentric circles is the wavelength. Since the circles are evenly spaced, we can see that the wave has a constant frequency.

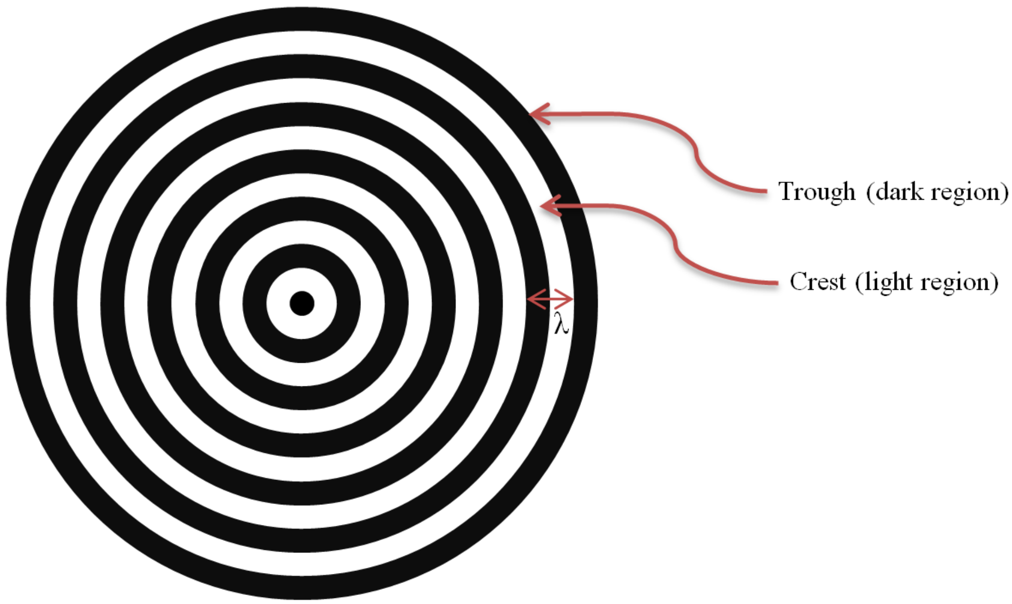

FIG. 4: Cross-sectional view of spherical wave fronts radiating at a constant frequency from point at the center

Similar to before, we can “add” these waves. This time, we’ll do it by investigating the interference pattern created by placing two of these sets of concentric circles (describing spherical wavefronts) on top of one another to see how they overlap. The pattern formed is sometimes called a moiré pattern. An example is shown in Fig. 5.

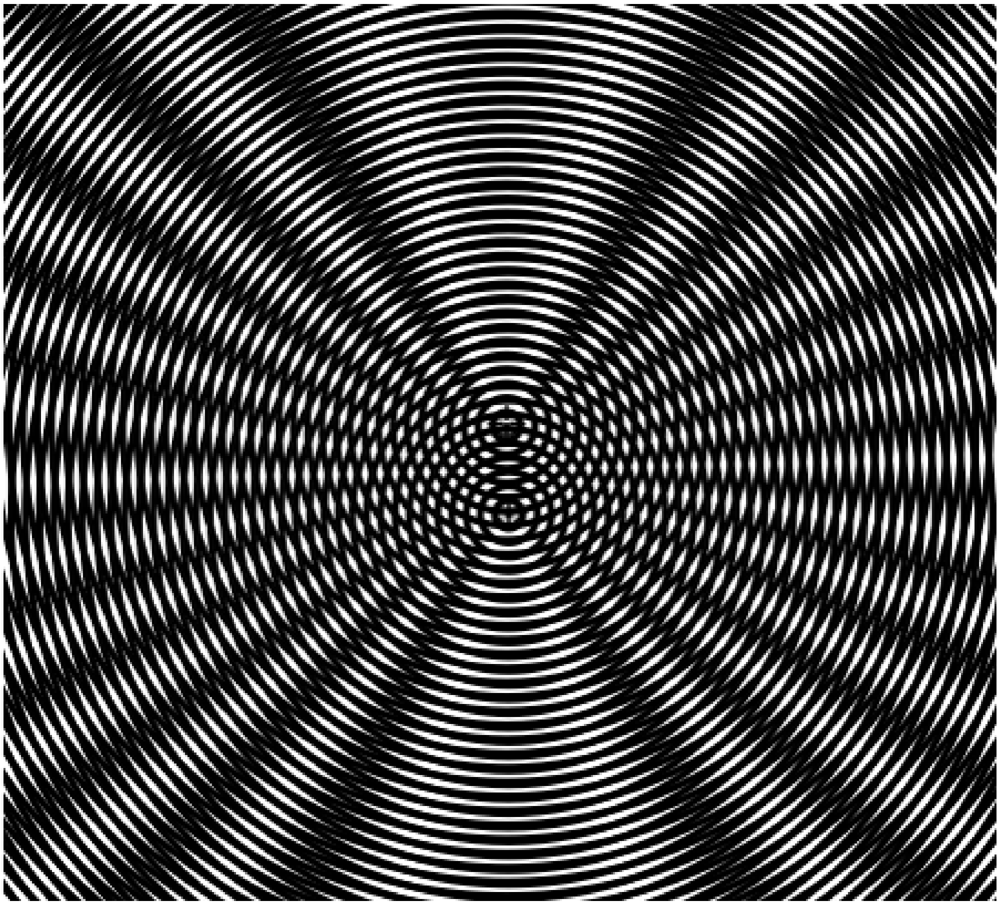

FIG. 5: Moiré pattern created by the superposition of two identical sets of concentric circles, representing spherical waves radiating from two points, in this case.[5]

While Fig. 5 gives a very clear diagrammatic example, real world examples can be found as well, like in the ripples of a puddle (see Fig. 6).

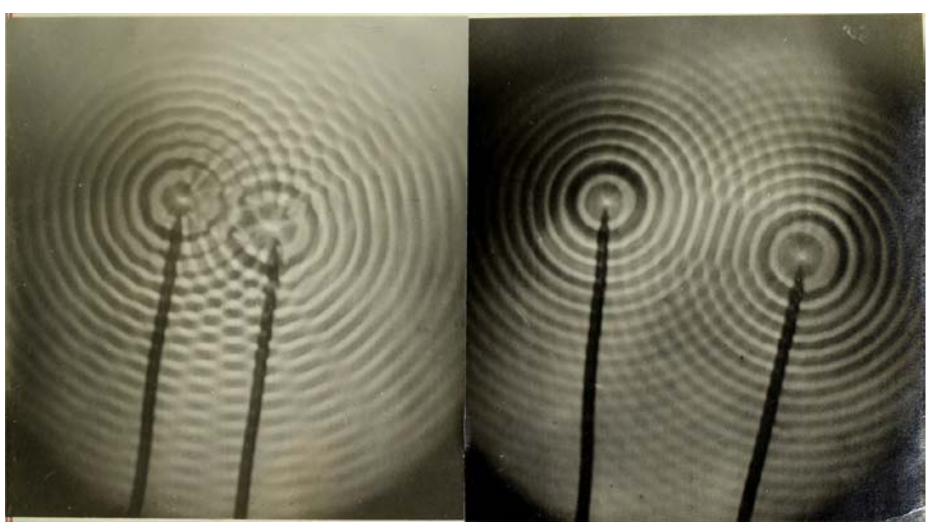

FIG. 6: Interference of ripples (small waves) of water from two sources of continuous waves emitted

at a constant frequency.[6]

If we trace along all of the light regions where there is constructive interference in any given interference pattern like these, we'll get a series of hyperbolas.[2] This is

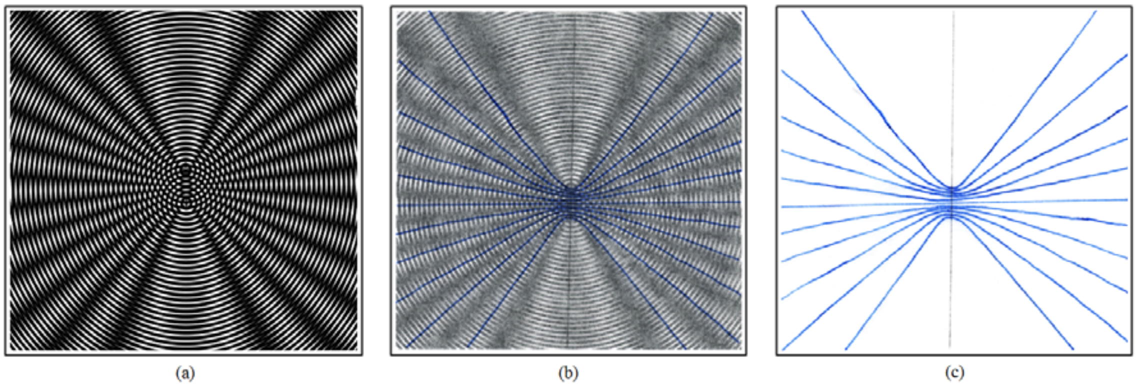

FIG. 7: Finding the set of hyperbolas associated with Fig. 5 (repeated in part (a)) by tracing the regions of constructive interference. Part (b) shows the traced lines on top of the original interference pattern. In part (c), the interference pattern was removed, leaving only the family of hyperbolas.

demonstrated in Fig. 7.

I've enlarged another set of hyperbolas like those shown in Fig. 7 and labeled their orders (by convention). I also labeled the locations of the point sources A and B. Assume that A and B are identical, each emitting waves of light at the same constant frequency. This is given in Fig. 8.

Imagine that the zeroth order line—the straight, vertical line, exactly in the center of the two foci A and B—is a mirror facing point A. Light from point B is equivalent to light from the image of point A reflected from the mirror.[2] As Jeong stated, "any ray of light arriving from source A … is reflected in such a direction as if it comes from source B," and vice versa.[2]

Next, imagine Fig. 8 were extended to three dimensions by rotating it 360 degrees around the axis that passes through both foci, and tracing out each hyperbola so as to create concentric bowl-like forms. If we were to coat any of these bowls with reflective material, thus, creating a hyperbolic mirror, then, similarly, the light from point B would

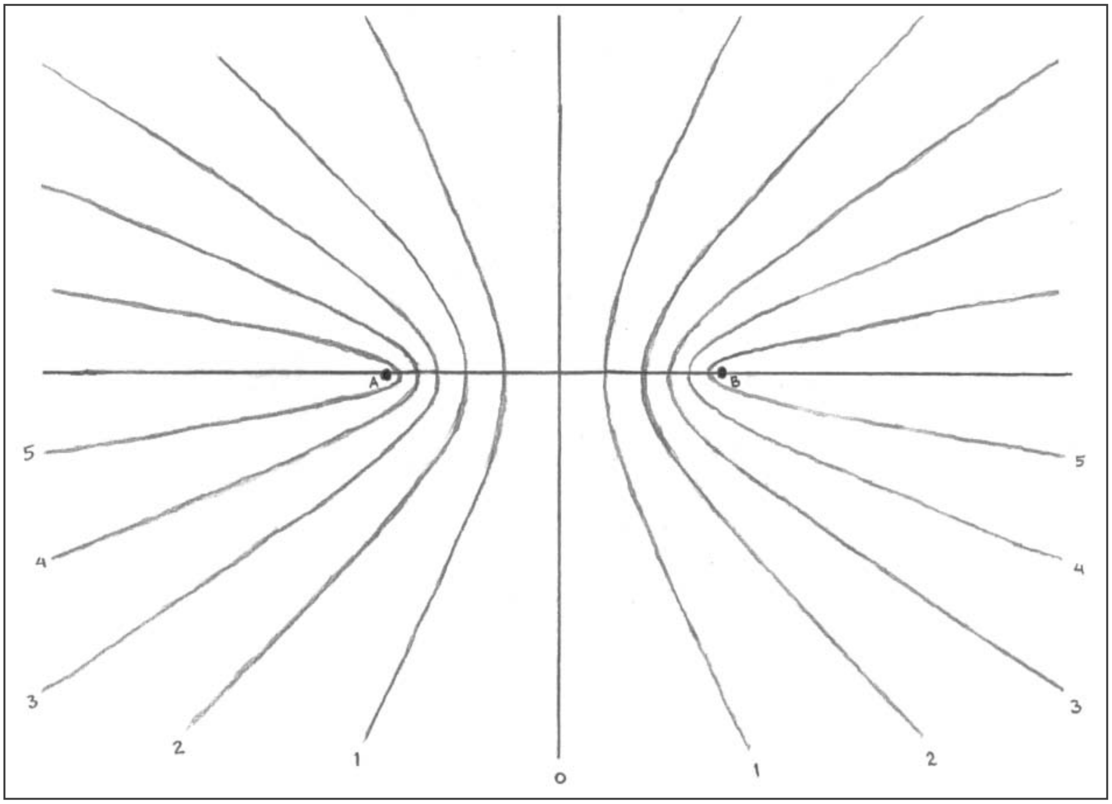

FIG. 8: Family of five hyperbolas associated with the interference of coherent waves from sources at points A and B.

be equivalent to light from the image of point A, reflected from that mirror.[2] That is, in Jeong's words, "a light ray arriving from source B will be reflected by any portion of any hyperbolic surface in such a direction as if it were generated by source A."[2] If the light source at B is replaced with some three-dimensional object or sculptural set of objects and is illuminated with light radiating from A, then complex, unique interference patterns will form, but the same principles that we've described for our simple case still hold.

Assume that we now place our light-sensitive holographic plate somewhere in this region of interference. We must recall that the coat of emulsion has some thickness which is substantial relative to the width of a wavelength of light (visible light has wavelengths only hundreds on nanometers long). The coat is often about ten times as thick as one wavelength, so hyperbolic surfaces of many different orders can be recorded inside.[2] We've established that a hologram is a recording of an interference pattern of coherent waves, so now we can conceptualize that the volume of the light-sensitive emulsion coating the glass or plastic sheet used to record a hologram contains a linear superposition of partially reflective hyperbolic mirrors, each created due to interference of the reference beam with light reflected from a point on the holographic object.[2]

Processing the hologram (that is, developing it similarly to a photograph in a darkroom) is what makes the recorded hyperbolic surfaces partially reflective.[2] After it is fully developed, it can be illuminated from the position of light source A. Assume that the source (or object) at B has now been removed. If the viewer looks through the illuminated hologram in the direction (relative to A and the film plane) where the point source B was located during the exposure of the hologram, then some of the light will be reflected in exactly the same way as it was when B was there.[2] Thus, the viewer will see a virtual image of point source B.[2] This is what allows us to view such strikingly realistic reconstructions of holographic objects and their environments—the light we see when looking at a hologram is identical to the light we could have seen when the object was present.

C. Fourier Model

While successful, impressive holograms can be created by individuals without a mathematical or scientific background, more rigorous mathematics are needed in order to do quantitative work. A formal understanding of holography can be achieved using Fourier analysis.[2] In Fourier analysis, complex waveforms are analyzed as sums of simple sinusoidal waves. Conceptually and mathematically, we separate these complex waves into the specific frequencies or "modes" which combine to form them.

While this type of analysis can be incredibly satisfying and helpful to the holographic scientist, the average display holographer (or artist interested in display holography) likely won't find a technical, mathematical description very beneficial, so I won't go into great detail here.

III. HISTORY

A. Origin

Dennis Gabor led the way in holography by presenting the basic concepts in 1948.[2] After going fairly unnoticed for about fifteen years, his work in holography began to generate new interest in the early 1960's. The invention of the laser in the early 1960s helped to pave the way for a holographic "renaissance,"[7] in which Gabor's fundamental ideas were explored and transformed into the holography more familiar to us today. By the early 1970's, holographers had successfully added color, motion, and 360-degree viewing to holograms.[8] Gabor's invention of the holographic method eventually earned him the Nobel Prize in physics in 1971.[2] Holographers like Emmett Leith, Juris Upatnieks, Yuri Denisyuk, and Tung Jeong, just to name a few, developed Gabor's basic holographic ideas into the "present" stage of holography: the holography that those of us in the know, know.[2]

While Gabor was driven by scientific endeavors to invent holography, in an attempt to correct spherical aberrations in an electron microscope[2], after holograms were presented in the public eye, the art world couldn't help but recognize holography as a new medium with immense artistic potential. By the early 1980's, there were holographers working artistically on display holography in countries around the world, like Britain, Sweden, France, China, and the Soviet Union, in addition to the United States.[9]

B. Place in Art History

Artists became interested in holography as an artistic medium in the early 1970's.[9] This was about the time when developments in holography (like new white light methods, and the Denisuyk method) were made which allowed some holograms to be viewed without a special light source like a laser.[9] This newly-broadened audience accessibility allowed for growth in display holography. This is not much of a surprise, since "holograms must be seen to be properly appreciated,"[9] as argued by Emmett Leith, an influential holographer during the first holographic revival.

1. Digital and Technologically-Based Media

Display holography is defined as "the recording and reproduction of three dimensional images on a flat film surface for the sole purpose of viewing."[12] In many ways, display holography is comparable to other technologically-based or digital art media, like photography, video, film, or virtual reality. Jeong showed that holography was just as feasible, and could be pursued at the same level as darkroom photography.[2] E. Leith claims to have "popularized the work by calling it lensless photography,"[9] an appeal to the public, tempting them with what's familiar. Holography has also been referred to as "laser photography".[8] It seems there is some truth to this.

Conceptually, holography and photography have similarities, and similar language can be used to discuss holograms and photographs. We can say that we "shot" a photograph or a hologram. In both cases, we often think that a moment in time has been recorded. We think of them as recording reality and truth, although this reality is cultivated, carefully composed, and often less than truthful. In this sense, a similar position of power comes along with working in either media.

Both holograms and photographs are recorded on film (or glass plates with one side coated in light-sensitive emulsion); holograms are made with silver salt emulsion, like very slow photographic film.[12] It's useful to use a light meter to help determine proper exposure settings in both fields. Additionally, holographic film is chemically developed like photographic film.[12] In both holography and darkroom photography, film is developed, stopped, fixed, and washed.[12]

Unlike photographic film, however, holographic film is developed to a uniform density (so the image does not "come up in the developer") and is sometimes bleached to increase brightness.[12] Also, holographic film has greater resolving power than photographic film (2000 to 4000 lines/mm compared to 200 lines/mm for a fine grain photographic film).[12] Additionally, there is no negative in holography comparable to a photographic negative. Holography doesn't use a camera, and there is no lens between the object and the film. This is because in order to properly record the interference pattern, "...every point on the film must receive light information from every part of the object."[12] A lens would prevent this by focusing the light to one point on the film.

When we take a photograph, we record information about the amplitude of the light reflecting off of the objects within that photo.[13] Then, when we look at that photograph, light is reflected off the photograph and into our eyes. Thus, we're given information about the amplitude of that light which once irradiated from the photographed object. Photographs can't tell us anything about the phase of that light, though. Holograms differ from photographs in this way, as they are reconstructions of both the amplitude and phase of the light irradiating from the holographic object at the time of exposure.[13] This information is contained in the fringe configuration of the interference pattern that technically makes up the hologram. Since holograms contain information about both the amplitude and phase of the light to which it was exposed, when illuminated, "...the resulting light field… would be indistinguishable from the original. This means that you would then see… the re-formed image in perfect three-dimensionality, exactly as if the object were there before you, actually generating the wave."[13]

On a different note, holography has some similarities to virtual reality. That is, a hologram does present a very convincing alternate reality, which must be placed within the physical reality that we're accustomed to experiencing. When we view a hologram, we see a virtual image of the holographic object, which was once present, part of our physical reality. Holograms are like windows to other realities, and those realities can range from mundane (like in the case of a true-color toy car or an ashtray) to incredibly surreal or abstract (like in Nancy Gorglione and Greg Cherry's *Teacup with Fish* or Joseph Burns and Serge Hononow's *Nested Arrays*, currently on display in the gallery).

While holograms don't have quite the interactivity that comes along with virtual reality, there is some sense of interaction or participation required, because different things within each artwork—each alternate reality presented—are visible depending on the way that the viewer chooses to look at it. Also, notably, virtual reality requires the use of equipment like a helmet and gloves. The added weight and presence of these things work to further separate the viewer from our usual physical environment. Holograms, however, don't require that special equipment be worn by the viewer, but rather that the lighting in the space around the hologram is adjusted just right. This helps to transform the viewer's environment in addition to presenting them with a window to another "reality". Ultimately, multiple spaces—the virtual space within the hologram and the physical space where we exist—are permeated and blended when a hologram is being illuminated for viewing. Virtual reality lacks this focus on blending of spaces; it seems to have more of a focus on mentally transporting viewers into a totally new space, a new reality.

C. Place at Lake Forest

Holography had a prominent—though perhaps unexpected—presence at Lake Forest College during the holographic revival of the 1960's and '70's. Our physics department was fortunate enough to have Professor Tung H. Jeong: inventor of the cylindrical hologram. His invention allowed for 360-degree viewing in holography, breaking past the limitations which make themselves quite evident when presenting a three dimensional image on two-dimensional film. Jeong is known to have said "If you're going to go 3D, why not go 360!"[10]

Beginning in 1971, Jeong hosted public holography workshops annually for about thirty years.[2] These workshops were international affairs, attended by hundreds of participants in the holographic community. Jeong started the "International Symposium on Display Holography, a triennial conference attracting scientists, artists, and businessmen from around the world," in 1982.[11] With the workshops and symposium, Jeong helped to bridge the gap between holographic scientists and holographic artists.[9]

As a result of these workshops and Jeong's presence in the holographic community, Lake Forest College has gathered an extensive collection of holograms made by dozens of holographers from around the world. Unfortunately, most of the collection has gone unseen in recent years. In an attempt to grant exposure to the impressive holograms within this hidden collection, I've worked over the past several months (with much help from holographer, Ed Wesly) to go through these hundreds of dusty holograms, properly illuminate each one for viewing, select the most technically interesting and successful holograms, and display them in the newly-expanded holography gallery in Lillard Science Center.

1. Curation of a Collection

The 2018 renovation of the Lillard Science Center left us with an empty, roughly eighty-foot hallway within the physics department, which we were to transform into a holography gallery. The hallway has a door at each end (so it can be entered from either side), one long wall, fit for hanging framed artwork, and two sets of large wooden cabinets along the opposite wall. We began by having lighting tracks installed in the ceiling, perpendicular to the long wall on which we planned to mount the reflection holograms. This would allow us to adjust the angle of incidence of the light on each hologram, which is absolutely critical when viewing them, as holograms cannot be seen properly (if at all) under ambient light.

Additionally, we had electrical outlets installed above the wooden cabinets, which would allow us to power diode lasers whose beams can illuminate laser transmission holograms. The cabinet outlets and hologram spotlights were wired to the same light switch at the gallery's entrances, so that visitors can easily adjust the gallery's lighting from the ordinary overhead lights to the spotlights and laser beams needed for hologram viewing.

We also had a thick, horizontal, matte black stripe painted on the long, empty wall, to give a dark, non-distracting background for the reflection holograms which we would later mount along this wall. Since brightness attracts our eyes, and some of the holograms may be relatively dim or tricky to illuminate, we aimed to minimize the stray light reflecting in the space around the holograms in order to give them an honorable presentation.

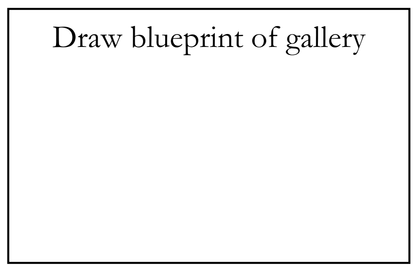

FIG. 9. Blueprint of gallery space.

We spent many weeks as holographic archeologists, carting multitudes of boxes, each filled with dozens of holograms, from storage in the basement up to our dimly lit laboratory, where we set up a single spotlight for viewing the reflection holograms, and a red diode laser for viewing the transmission holograms. We carefully illuminated each of these hundreds of holograms, one by one, discovering the alternate realities that they held. Ed had fascinating and insightful stories to share about many of them along the way.

The range of images which we uncovered was quite dramatically diverse, from simple everyday objects, like a meter stick lying on a table, to bubble holograms used for scientific research at Fermi National Accelerator Laboratory; from portraits of holographers, Lake Forest College physics personnel, and public figures of the past, to thoughtfully and artistically composed sculptural scenes, and even striking abstractions of color and form in deep space.

Ultimately, after much deliberation and examination, we selected twenty white light reflection holograms and thirteen laser transmission holograms to display in the gallery.

We framed each hologram (unless already in its original frame from the artist) in a thin, black, metal frame, and matted those of the reflection holograms which we felt needed mattes, based on size and placement of the composition on the film or glass plate.

After measuring each white light reflection hologram’s reference angle, we mounted them all along the wall, with their centers at about sixty inches from the floor (an average eye level). We then worked to illuminate each hologram using the spotlights in the tracks along the ceiling, perpendicular to the wall of reflection holograms. We used trigonometry to determine the distance between the spotlight and wall of holograms that we predicted should maximize the brightness of each hologram. We then moved each light closer to or further from its corresponding hologram based on the reference angles we measured and the distances we calculated, in addition to our empirical judgements about when each mounted hologram appeared brightest.

All of the white light reflection holograms which we worked to include in the gallery have been photographed, and these photos are presented in the following figures. They’re pictured in the order that they appear in on the wall when the gallery is entered from the west side. The first hologram displayed is a portrait of Dr. T. H. Jeong, made by the Holicon Corporation in Evanston, Illinois around 1988. It’s a white light reflection copy from a pulsed laser transmission master hologram.

We chose to place this portrait of Jeong at an entrance of the gallery as a way to pay homage to Jeong, since this project probably would not have been possible were it not for his efforts in the field of holography. I'm grateful for his recognition of the fruitful ties that exist between the worlds of science and art; he took aspects from both to make both fields even better. One of my main intentions for this gallery is to inspire others to see these connections as well.

Objectively, this is a well-executed portrait which shows the incredible detail typical of a successful holographic portrait. We can see individual hairs on Jeong's head and face, and every wrinkle and fold in his skin. We also see the somewhat wax-like quality of the skin that is often critiqued in holographic portraits.

Notably, most affordable, accessible lasers are only powerful enough to properly expose holographic film after many seconds of exposure. When exposure times are long, even a very small amount of motion of the object (from the reference point of the film or holographic plate) will destroy the interference pattern that makes up the hologram, and instead of an image, black fringes (stripes) will take over the whole hologram. We'll lose all visual information. With short enough exposures, there is not enough time for this type of destructive movement to occur. Thus, more powerful lasers, like ruby lasers, can be used to reduce this exposure time. Therefore, I assume that a very powerful laser was used to create the initial laser transmission master hologram which was copied to create this white light reflection hologram. (The same technique was used in a number of the artworks in our gallery.)

FIG. 10: ***Portrait of T. H. Jeong*** **(1988) by the Holicon Corporation**

Following Jeong's portrait is a portrait of Boy George, the lead singer and persona in the pop group 'Culture Club,' made at Richmond Holographic Studios in London, England in 1985. It, too, is a white light reflection copy from a pulsed laser transmission master hologram. This is a monochromatic green, close-up portrait of the post-modern persona. He's painted white, with dramatic black makeup, and a pattern of small black spots covering his hands and adorning his face. His extra-long eyelashes reach forward, out of the plane of the hologram and into the viewer's space.

This portrait is part of a series of at least three holograms made by Edwina Orr (in collaboration with Boy George) at Richmond Holographic Studios. When searching for information about this hologram, all that I was able to find online was about two very similar portraits in which Boy George is wearing the same clothing and makeup. One of these is composed similarly to the portrait in our collection, but he's resting his chin on his fists, exposing the pattern of black dots covering the backs of his hands. This one is in the Jonathan Ross Hologram Collection.

The third hologram in the series is a wider shot including Boy George's shoulders. He's wearing a spotted scarf and hat, in addition to the rest of the harlequin look. Large orchids were placed next to his head in this composition. All three of these portraits are artistically composed, and were clearly made with quite a different intention than the very traditional portrait of Jeong shown previously. This contrast (even between two white light reflection portraits containing fairly similar subject matter and made in very similar ways) helps to elucidate the many artistic possibilities that holography can facilitate.

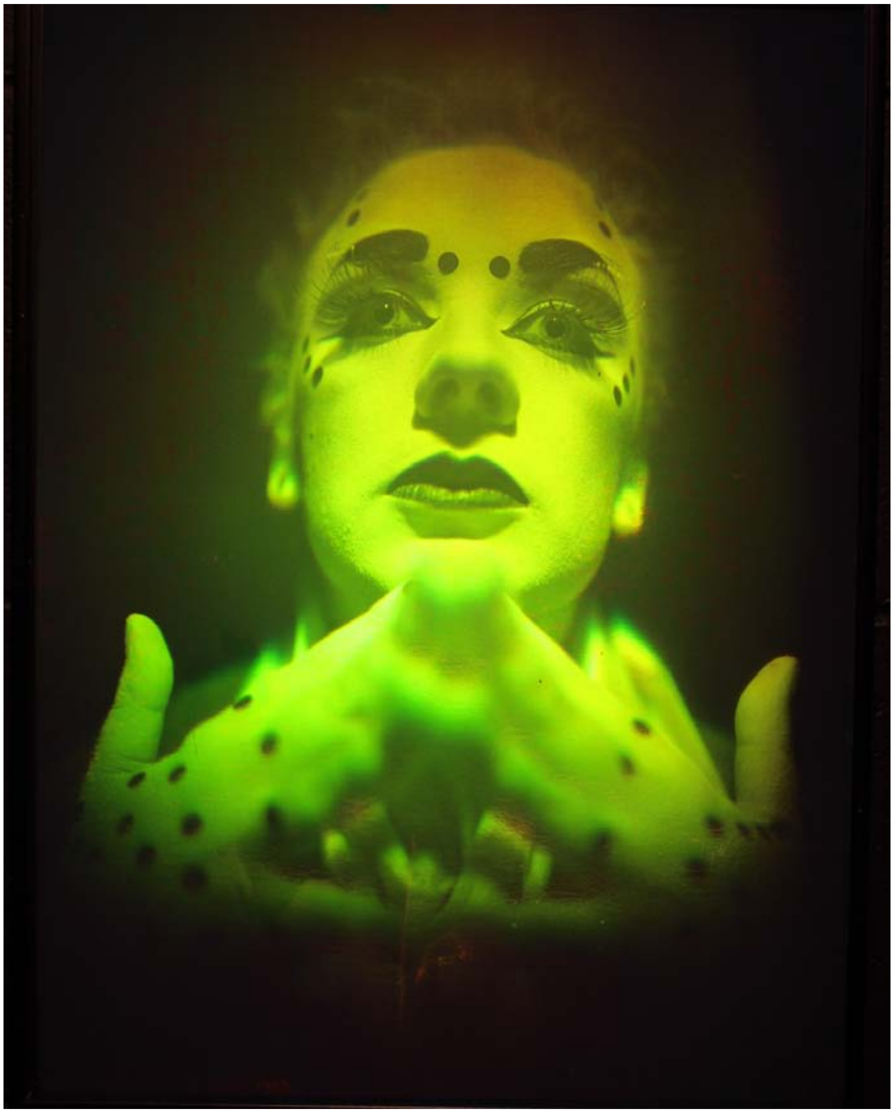

FIG. 11: ***Boy George*** **(1985) by Edwina Orr and Richmond Holographic Studios**

The third hologram in the gallery is another white light reflection copy made from a pulsed laser transmission master hologram, made by the Bernadette and Ron Olsen in 1992. It's titled *Kim Budil*.[14] It is a somewhat abstracted nude, in which the model is sitting with her arms wrapped around her folded legs.

Ed believed that this hologram was made by Fred Unterseher, and that this was a portrait of Unterseher's wife, "Becky" (Rebecca Deem, another holographer). However, the references I've found say otherwise.[14]

The Olsons directed the reference angle such that the hologram would have to be viewed sideways, with the model's back upwards, and her shins toward the ground. This, along with the gradients from red to green and back to red across the hologram, work to abstract the hologram a bit, directing us to focus more on texture and form within the composition than on the literal subject matter, a woman's body (although we can see that it is a woman's body, and this certainly affects the tone of the work).

The model's skin is rendered in breathtaking detail—we can see the light reflecting off of each individual hair on the model's arm, and the flesh appears almost tangible. This hologram presents an incredibly intimate and compelling image, illustrative of some of the possibilities for holograms including the human body, one of the art world's most common and timeless motifs.

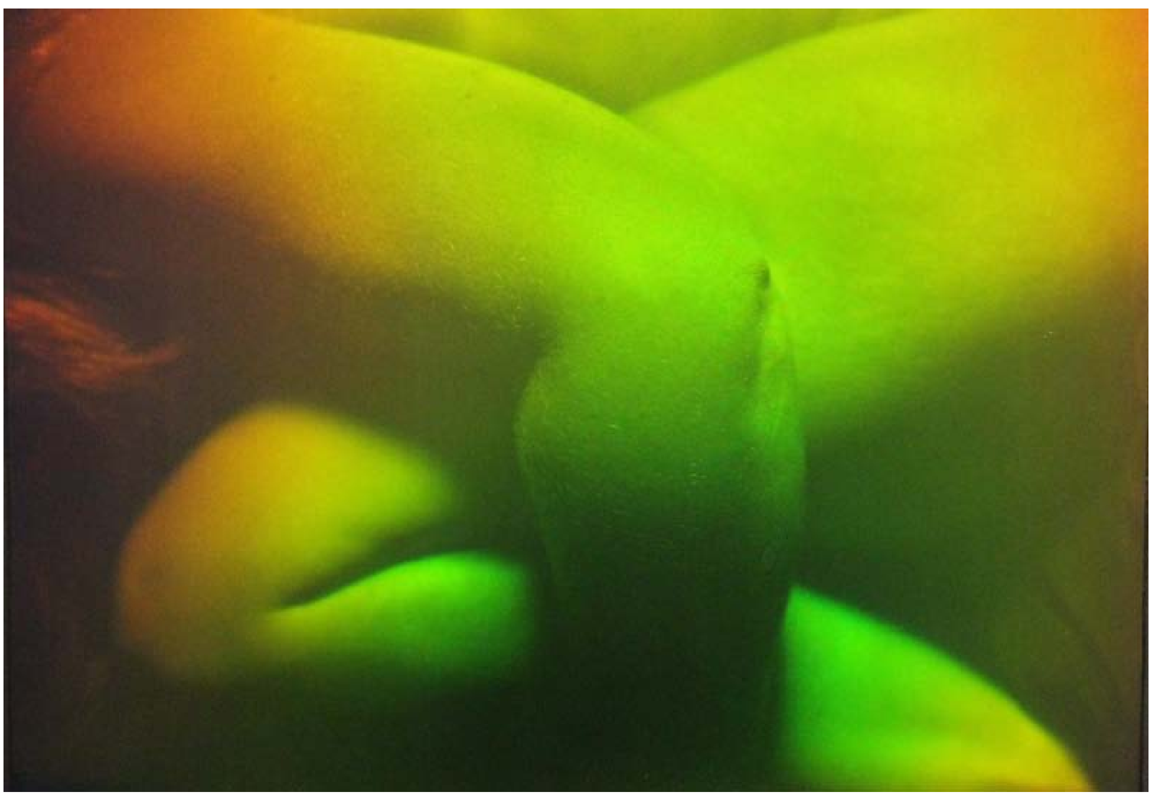

FIG. 12: *Kim Budil* (1992) by Bernadette and Ron Olson

Fourth is a hologram called *Your Beer Companion*, created in 2002 by Geola, a company which started in Vilnius, Lithuania in 1995 as "General Optics Laboratory," and now sells optical equipment and holographic materials.[15] (Actually, it appears that this composition can still be ordered from Geola's website today.)[15] *Your Beer Companion* is an animated, digitally printed hologram which Geola calls an "i-Lumogram."[15] In other words, it's a video capture that was digitally turned into a hologram.

It depicts a young man in a striped, button-down shirt, red vest, a loosened tie, and a headband. He pours a beer from a bottle into a glass. As we move past the hologram from left to right, we can see the glass fill up, and the man smiles and winks as we approach the rightmost viewing angle (When walking the other way, of course, he winks, then the beer appears to flow back upwards into the bottle).

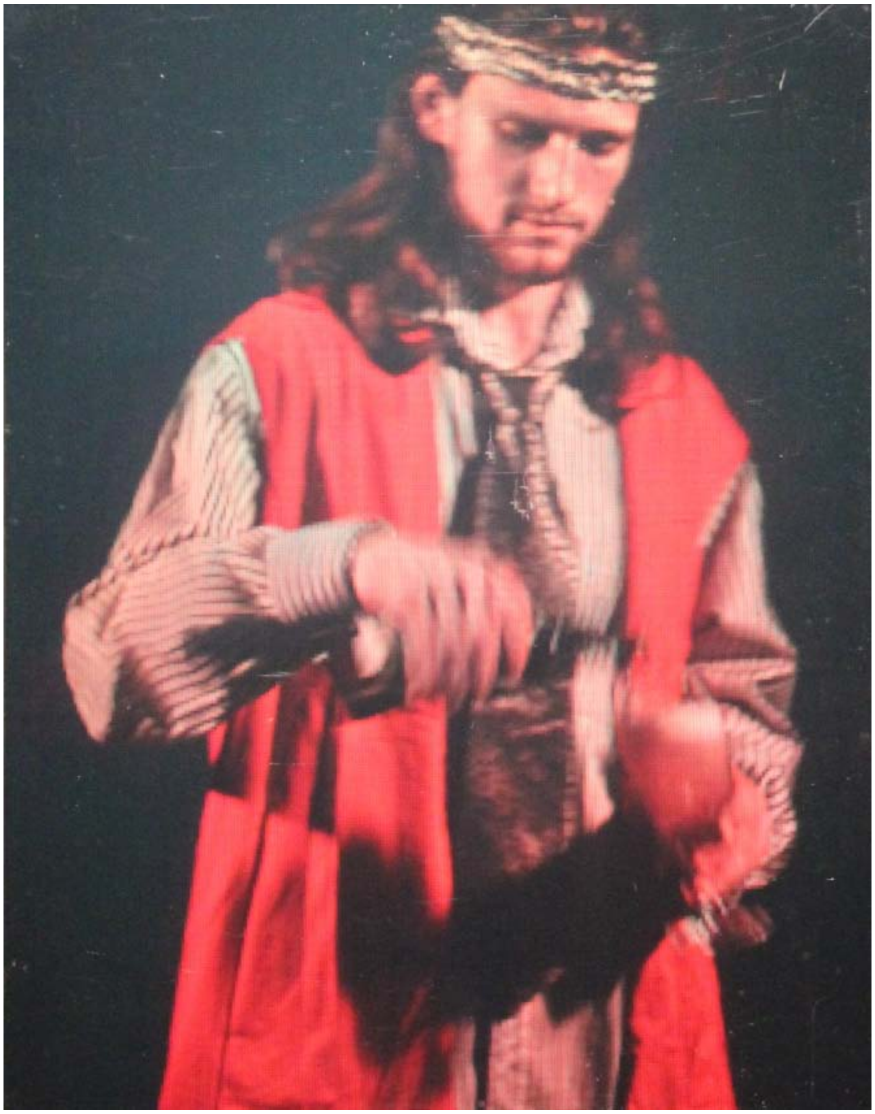

FIG. 13: ***Your beer companion*** **(2002) by Geola**

The fifth hologram in the gallery is *Michael's Portrait*, made by John Perry in 1984.[16] This is a white light reflection hologram. It is clearly a very different type of portrait than the traditional portrait of Jeong by the entrance, or even the more artistic portrait of Boy George which follows. *Michael's Portrait* depicts a glass head-shaped hollow form which appears to be illuminated from within, sitting in an abstract, intangible space.

Since, in this case, the holographic object is rigid and inanimate (unlike the human forms we've seen holographed thusfar), the Perry didn't have to worry very much about it moving during the exposure time. Thus, this hologram could be made with a less powerful laser using a longer exposure time and white light reflection techniques.

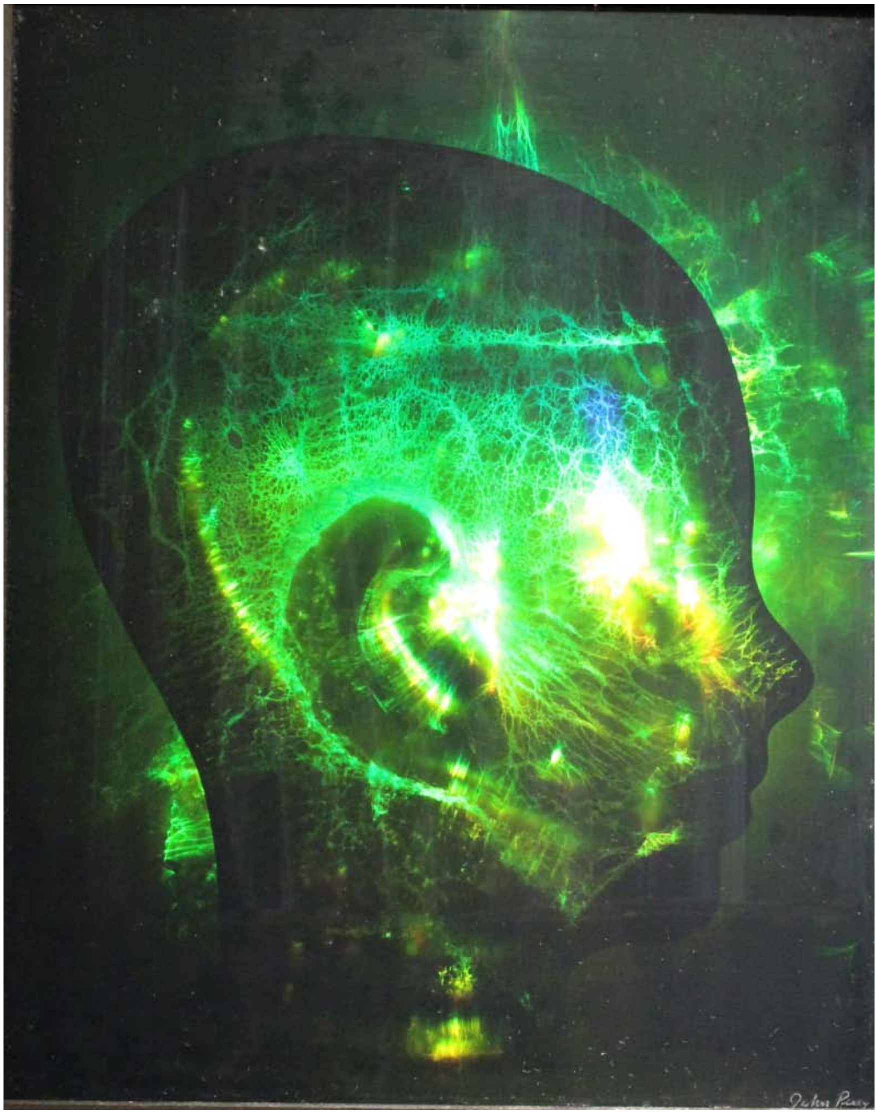

FIG. 14: *Michael's Portrait* (1984) by John Perry

Sixth is another example of an abstracted portrait: Kenneth Harris' 1982 white light reflection holographic take on *Mona Lisa*. Harris simplified Leonardo Da Vinci's *Mona Lisa* into a basic, two-value form, then duplicated it. One of these forms appears to sit back behind the picture plane, while the other is enlarged and appears to ascend forward far beyond the holographic plate. This hologram shows incredible depth.

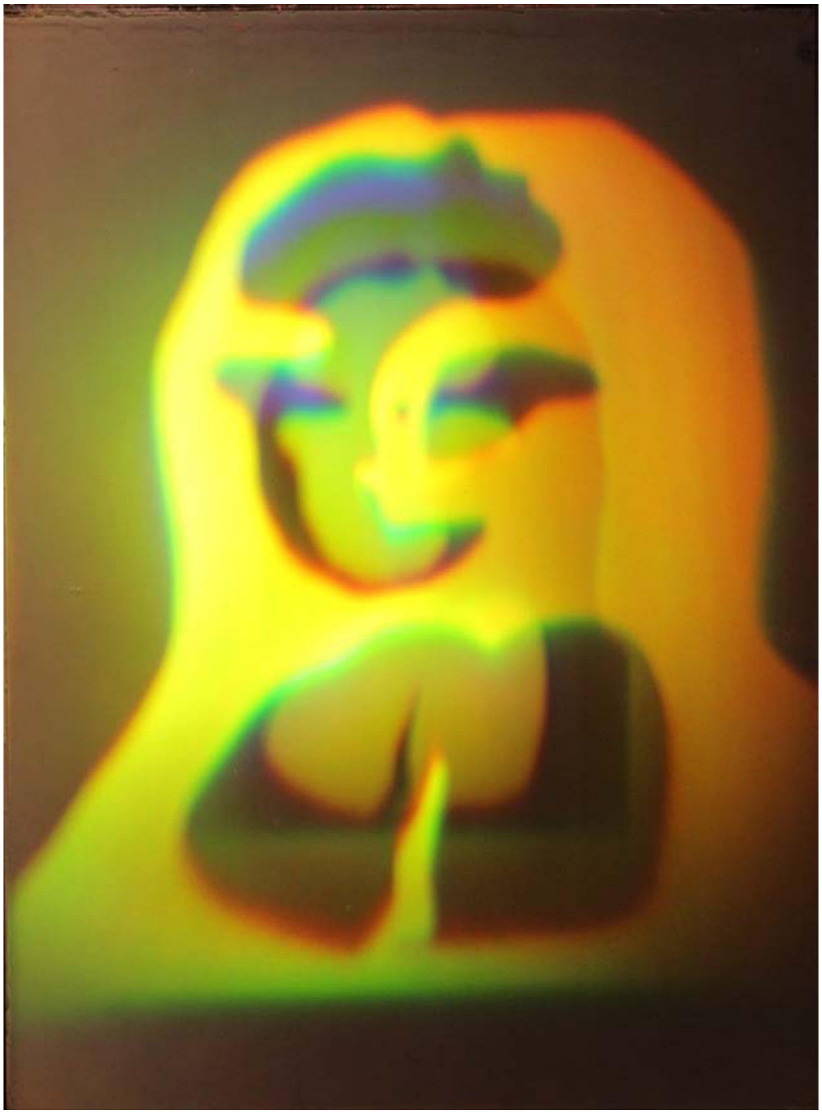

FIG. 15: *Mona Lisa* (1982) by Kenneth Harris

Seventh is Pierre Boone's *Xylophone Interferogram*, made in 1988. Boone is a Belgian scientist who, like Jeong, worked to meld the science and art communities.[14] The hands in the bottom left corner helped us to determine that this was a hologram by Boone, as he included his hands in his holograms quite often. Boone studied pulsed holography, and created a number of compelling compositions such as this one. Very powerful lasers are used in pulsed holography, which require very short exposure times. This allows holographers to capture objects without rendering them motionless. Boone’s signature of holding the holographic object and including his hands in an edge of his holograms would not be possible without the techniques of pulsed holography which shortened exposure times.

This particular hologram by Boone is a doubly pulsed single beam reflection hologram; “150 μs” is written on the top right edge of the film in permanent marker, so we assume that’s the time between pulses. That is, a pulse of light exposed the holographic film, then 150 microseconds later, a second pulse exposed the film once again. The resulting hologram has interference fringes on the areas which moved in the 150 microseconds between pulses. Therefore, this type of hologram is called an “interferogram”. It allows us to see that the xylophone was probably ringing during exposure, because the high contrast stripes on the keys show that they were vibrating.

FIG. 16: ***Xylophone Interferogram*** **(1988) by Pierre Boone**

Eighth is this composition by Larry Lieberman, made in 1989 in Miami, Florida. It's a multicolor white light reflection hologram depicting an artistic representation of cells in the human body. Unfortunately, we don't know much about this hologram, and I was unable to find any sources to provide additional information. Ed noted that he recalled hearing that it was a depiction of the AIDS virus attacking a T cell. Anyhow, it is an interesting and successful artistic representation of scientific content. It removes barriers, blending art and science, which fits my objective.

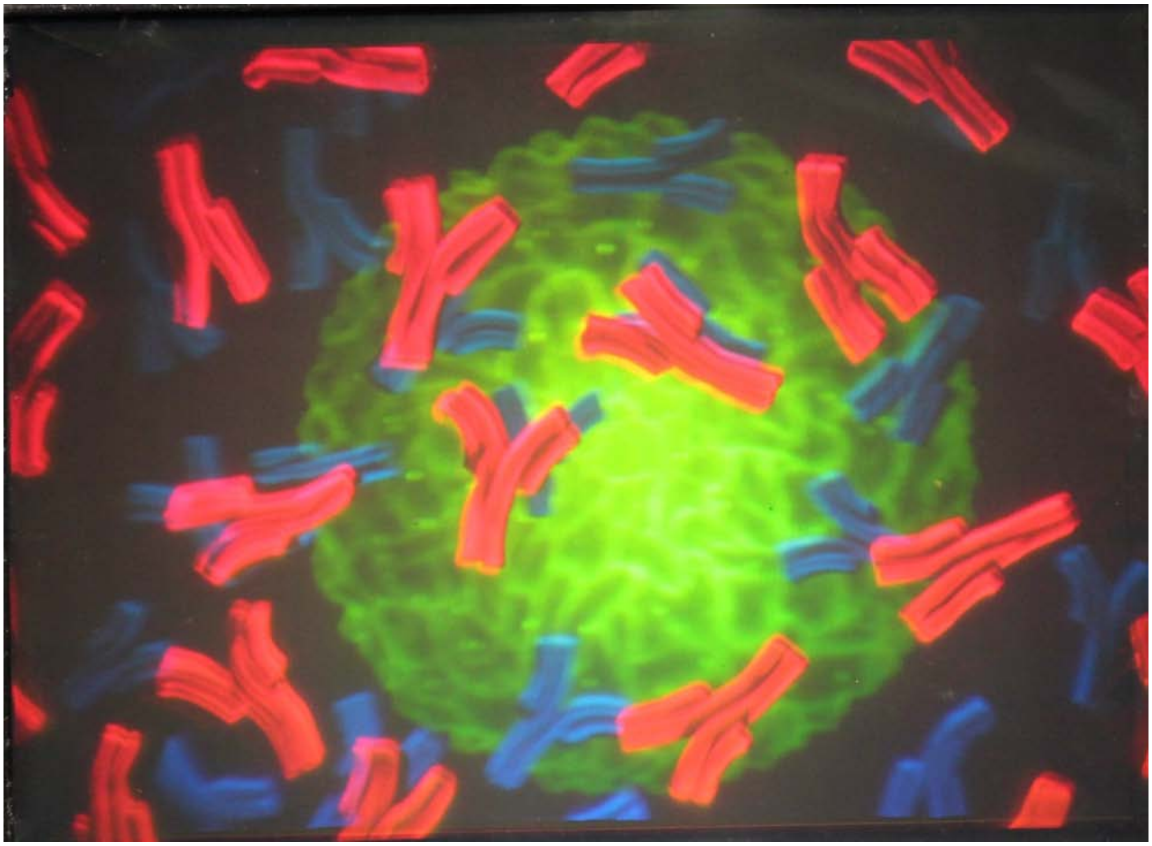

FIG. 17: ***Untitled*** **(1989) by Larry Lieberman**

Ninth, we have *Saturn*, made by Lon Moore in San Francisco, California 1978. *Saturn* is a small white light reflection copy form a laser transmission master hologram. This particular composition is very deep (despite its small size-- at 3.5 by 5 inches, it's the smallest reflection hologram on display in the gallery). While sitting in the shimmering space which makes up the background, Saturn sits dominates the composition, its ring projecting about 3 inches out of the picture plane. Again, like the previous hologram depicting the T cells, this hologram combines the topics of art and science, consequently benefiting each.

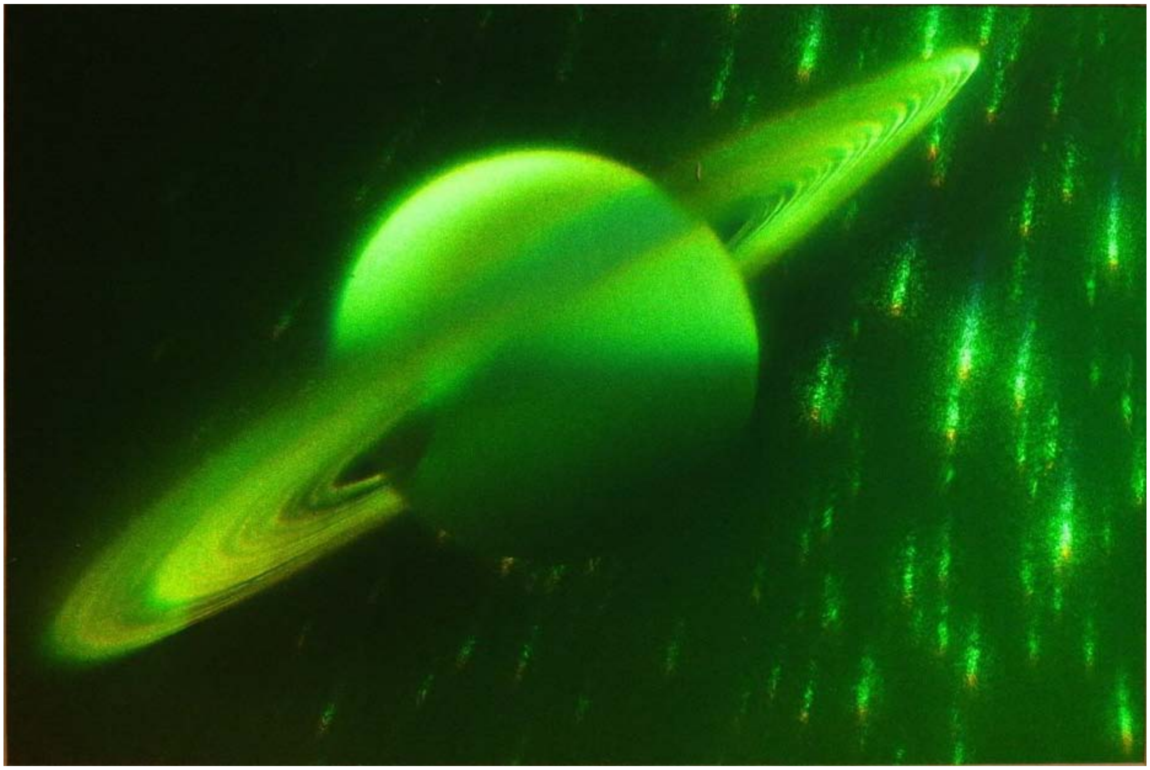

FIG. 18: *Saturn* (1978) by Lon Moore

The tenth hologram displayed is another white light reflection hologram from a laser transmission master. This hologram is from a series of scenes from *Alice and Wonderland* by the French holographers Jonathan Collins and Pascal Gauchet in 1984.[16] I'm assuming the artist and year based on similarities to another hologram pictured in the 1985 International Exhibition of Holography's Catalogue of Holograms.[16] This similar hologram is now in the Jonathan Ross Hologram Collection.[17] I believe that these are part of the same series, since both contain the same doll (presumably Alice), and the holograms are the same size and format. Additionally, Ed recognized the doll as Alice immediately upon viewing the hologram.

FIG. 19: ***Alice in Wonderland II*** **(1984) by Jonathan Collins and Pascal Gauchet**

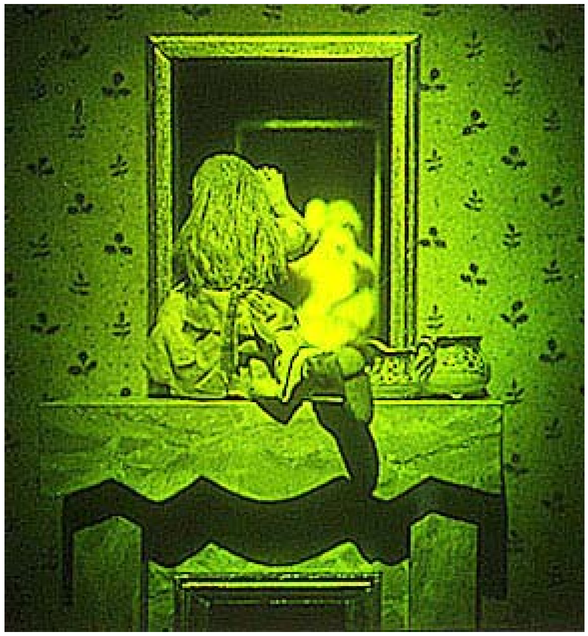

FIG. 20: ***Alice in Wonderland I*** **(1984) by Jonathan Collins and Pascal Gauchet**

The eleventh hologram in the gallery is Nancy Gorglione and Greg Cherry's *A Cup of Gold Fish* from 1992.[18] This is another white light reflection copy from a laser transmission master hologram. The hologram depicts a ceramic teacup and saucer sitting on a small table. When viewed from above, we can see that there are fish swimming inside the teacup. A cloudy haze is created throughout the composition, which appears to be created with fiber filling (a medium that I often use in my own work). Additionally, by peeking behind the table, the viewer can see the Dupont Photopolymer logo, a tribute to the holographic film used to create the hologram. This is a strong and surreal composition which emphasizes depth and encourages the viewer to move. Thus, it makes use of features unique to holography as a medium.

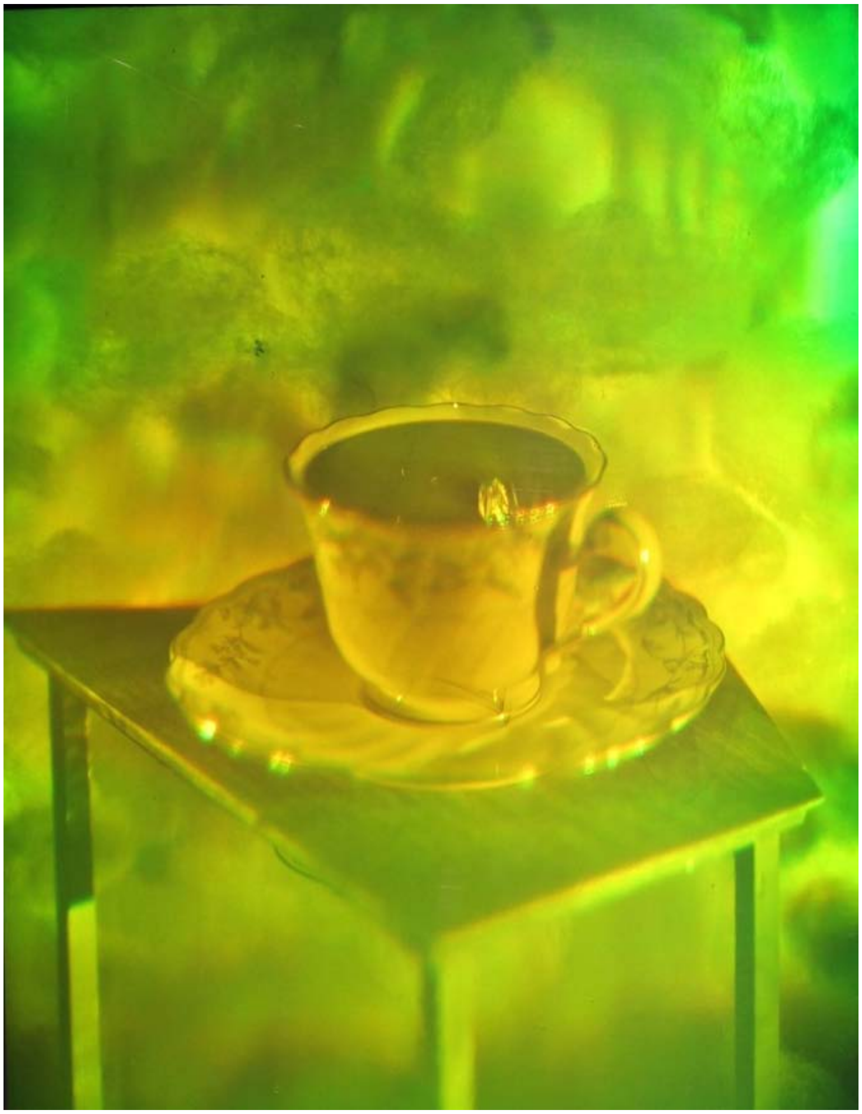

FIG. 21: ***A Cup of Gold Fish*** **(1992) by Nancy Gorglione and Greg Cherry**

Twelfth, we see American artists Joseph Burns' and Serge Honinow's *Nested Arrays*, from 1981.[19] This is a mirror-backed white light reflection hologram, sometimes referred to as a "rainbow hologram." The composition includes the basic structural beams which make up three concentric box-like forms, connected at the corners. A shadow appears below the form. The form has a color gradient from violet at the top, through all the colors of the rainbow, to red at the bottom on the hologram (although these colors shift depending on the location of the viewer and the position of the spotlight).

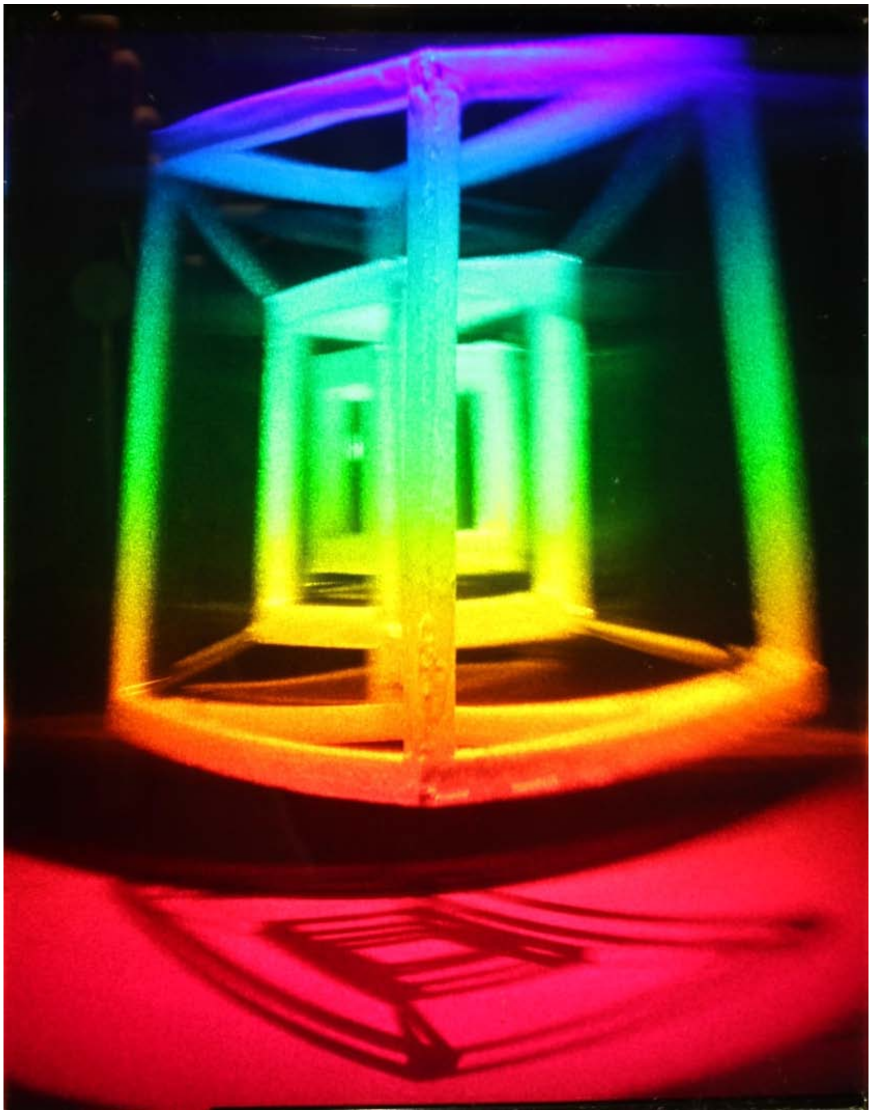

FIG. 22: *Nested Arrays* (1981) by Joseph Burns and Serge Honinow

Thirteenth in the gallery is an untitled computer-generated white light reflection hologram made by Nick Phillips in 1988. As Jeong explained, "...the mathematics of holography is well-known and the pattern actually recorded on the photographic film during the formation can be calculated and plotted out by a computer."[2] With this hologram, Phillips, "created the world's first home micro-computer generated holographic stereogram using a Commodore Amiga computer and Sculpt 3D software. The images were output to film and the hologram was recorded using an early holographic stereogram recording system designed and built by Prof. Nick Phillips."[20]

Formally, this hologram appears fairly diagrammatic since all forms are composed only of a simple line-based structure showing their contours. Notably, though, it contains motion as the viewer moves from side to side. A large bird flies above a structure of block letters that spells "AMIGA" (a reference to the computer used to form this holographic image. Also pictured is a falling ball, a large flower bud shaped structure, and a clear horizon line, all on the flat black backdrop.

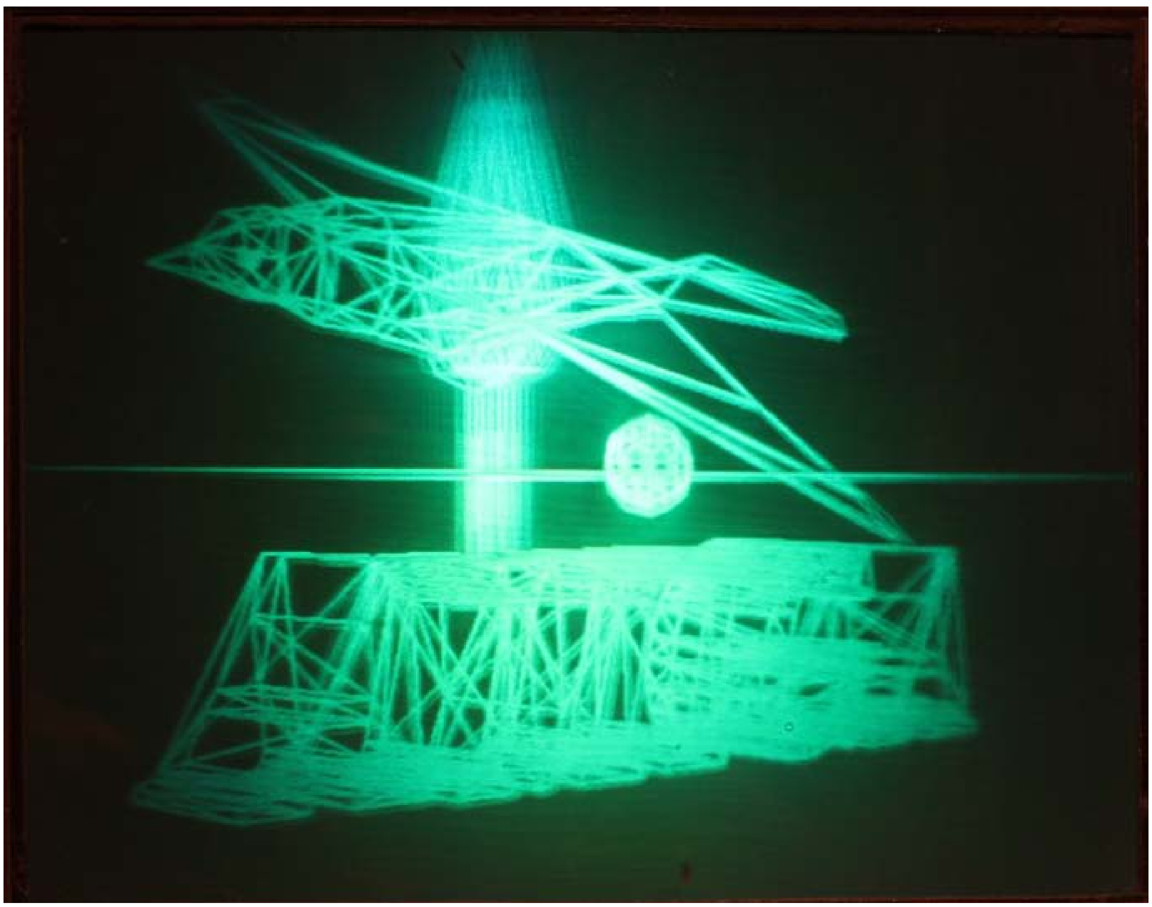

FIG. 23: *Untitled* (1988) by Nick Phillips

The fourteenth hologram displayed is another computer generated white light reflection hologram, similar to the last hologram, although much more detailed and less abstract. This time, some sort of insect is presented, magnified hundreds of times to a fairly off-putting size, much larger than life. While this image and the previous image were created using very similar methods, the types of images vary drastically, conveying that the possibilities which arise when working with computer generated holography are quite broad.

FIG. 24: ***Untitled*** **(1988) by Nick Phillips**

Fifteenth is Larry Lieberman's *Abstract*, from Miami, Florida in 1989. It's a multicolor white light reflection hologram depicting overlapping translucent crystalline forms. These forms emphasize the depth within the composition, and show that the optical properties of the diffracting crystals are retained within the hologram—a property of holography which, I believe, allows for great artistic possibilities unique to this medium.

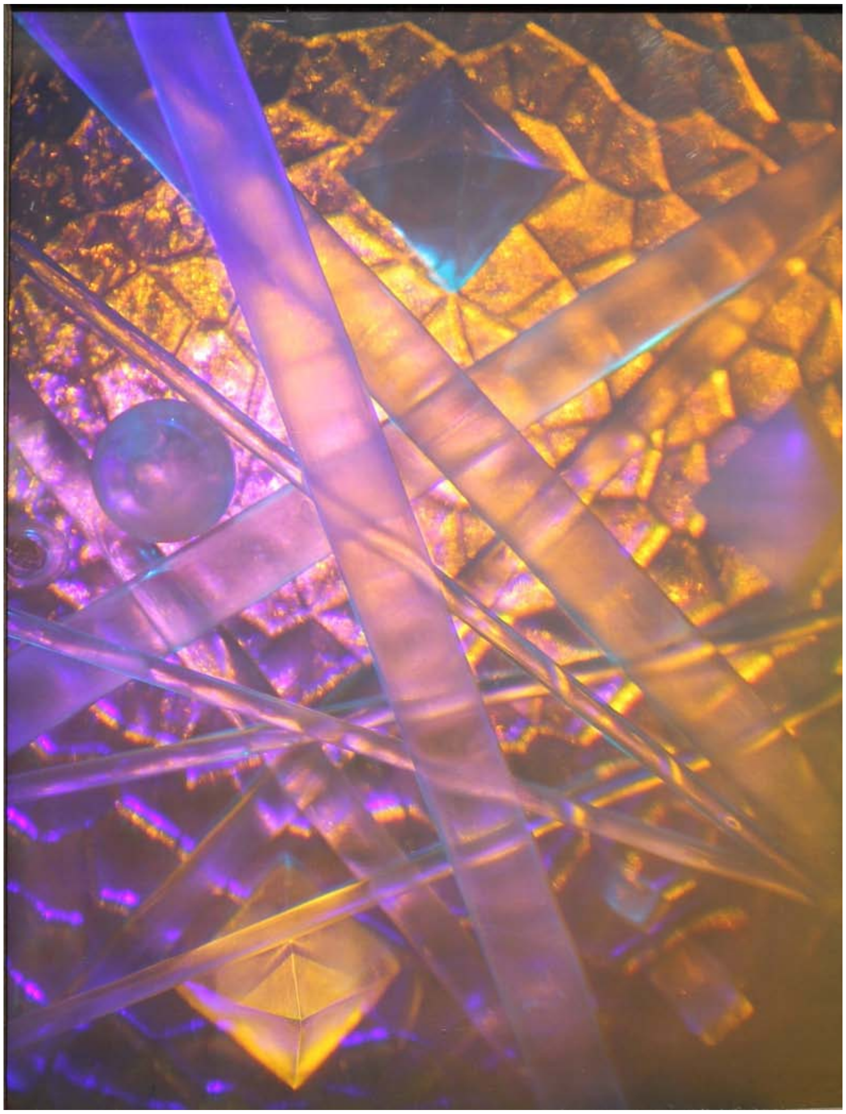

FIG. 25: *Abstract* (1989) by Larry Leiberman

Sixteenth, we have a single beam reflection hologram of a circuit board, made by Richard Rallison in 1991 in Salt Lake City, Utah. This is a strikingly bright hologram on a clear glass plate. I almost regret framing it, because now viewers struggle to believe that there's not actually a circuit board behind the glass; this was easier to prove convincingly when it was possible for the viewer to swipe their hands behind the hologram, only to see them through the translucent circuit board. There isn't much (if any) written documentation available about this hologram—it may have been seen as more of an experimental byproduct than a work of art upon its creation. Nevertheless, technically, it's an extremely successful hologram which presents an incredibly convincing image of the holographic object.

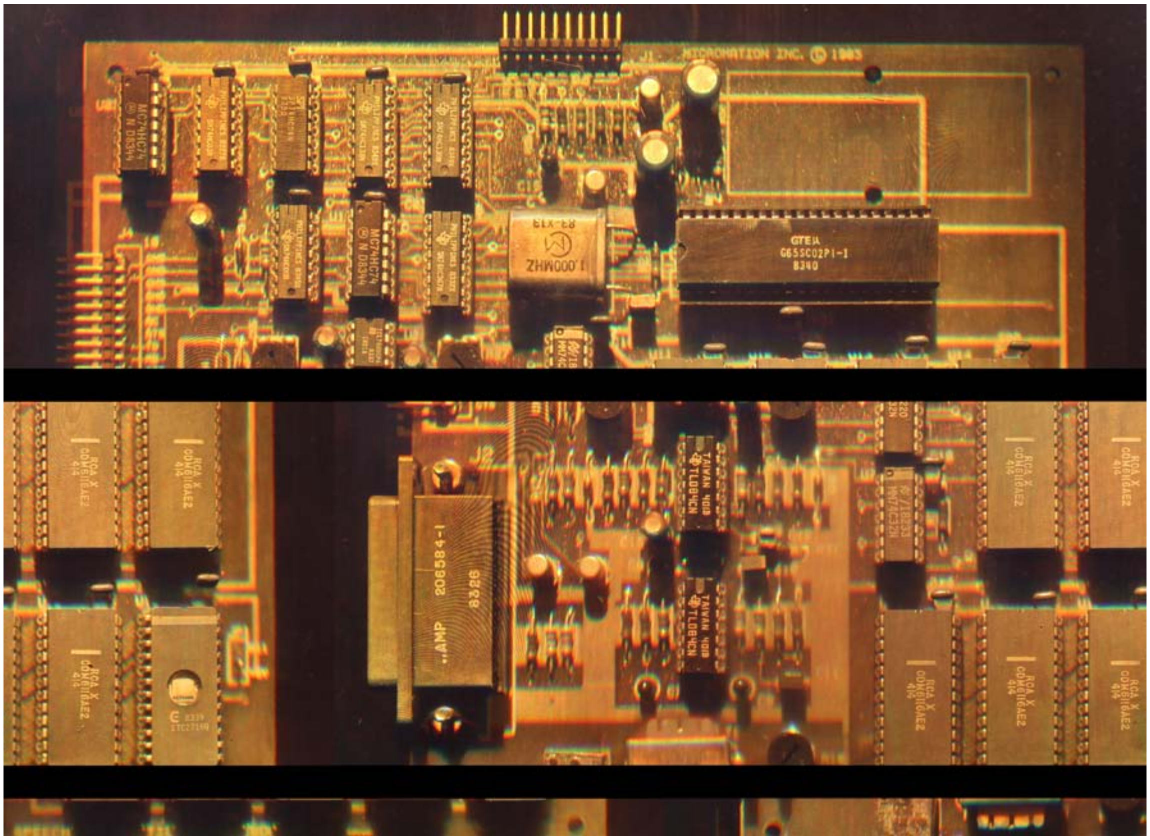

FIG. 26: ***Circuit Board*** **(1991) by Richard Rallison**

Seventeenth is Hans Bjelkhagen's *Golden Leica*, a white light reflection hologram made with the Denisyuk method in 1981. The holographic object here is a Gold Edition Leica M4-2 (Leica made 1000 limited edition M4-2's plated in 24 carat gold). Initially, we thought that this was a conceptually interesting hologram because it references darkroom photography, a medium so akin to holography, yet so clearly different. Otherwise, we didn't have any information about this hologram, until we were visited by Bjelkhagen himself, who was able to provide helpful context.

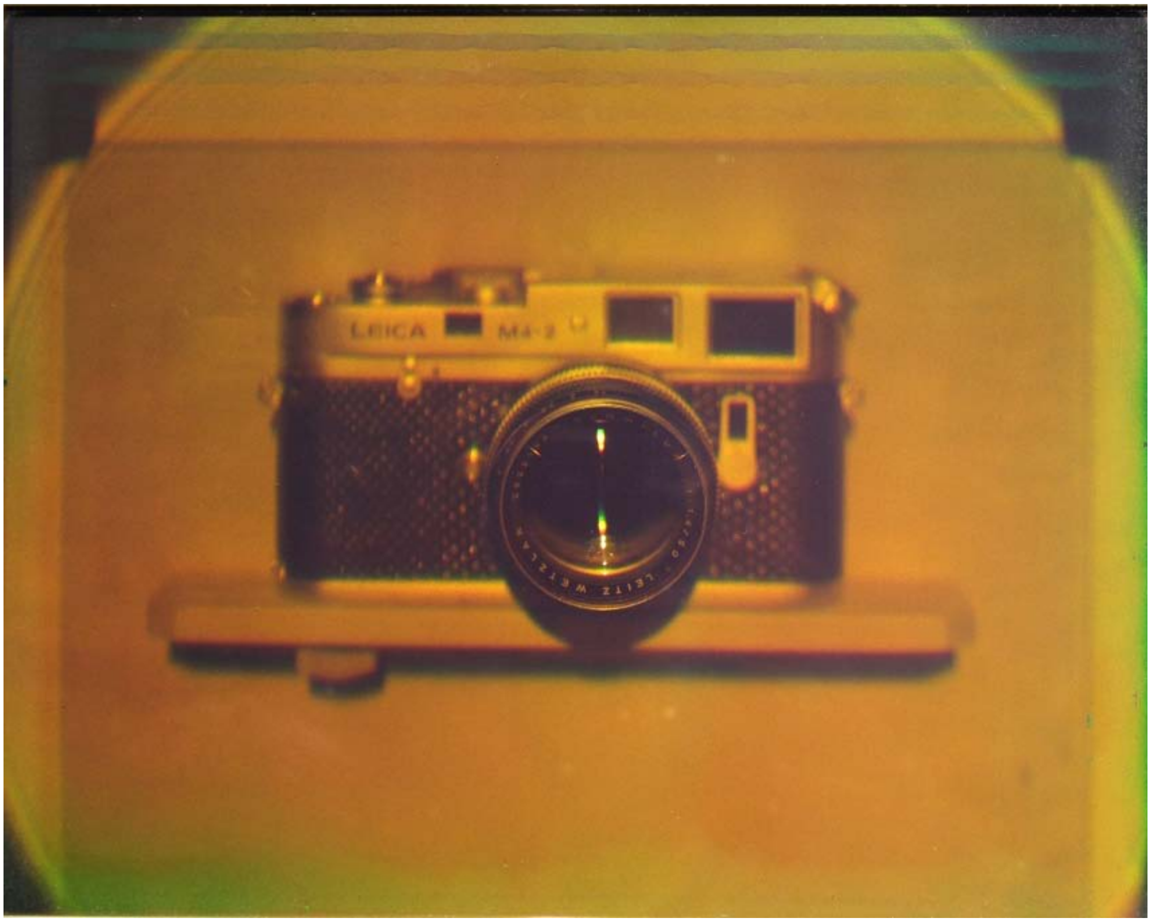

FIG. 27: ***Golden Leica*** **(1981) by Hans Bjelkhagen**

The eighteenth reflection hologram is next to the second entrance (or exit) of the gallery, so we thought it would be fitting to choose this hologram of the 1991 International Symposium On Display Holography participants standing in front of Durand Art Institute at Lake Forest College, many of whom are waving, as a sort of farewell, or a warm welcome to holography at Lake Forest College, depending on the viewer's path. This is a multicolor embossed holographic stereogram made in Chicago, Illinois by Steven Smith (also known in the holographic community as "Lasersmith").

The creation of holographic stereograms like this one (and also Nick Phillips' computer generated hologram of the bird flying over the word "Amiga") requires a very different process than is used to make ordinary reflection or transmission holograms.

According to Michael Halle, “a holographic stereogram records a relatively large number of viewpoints of an object and uses a hologram to record those viewpoints and present them a viewer.”[21] So, holographic stereograms are unlike other holograms, in which all of the optical information from the time of exposure is recorded, meaning that we can see the holographic object from every accessible viewpoint. Instead, holographic stereograms have a finite number of views determined by the holographer. These can be captured using an ordinary camera, and synthesized to a hologram later using computer graphic techniques.[21] This is why it was possible to make a hologram like this, of a large, outdoor space full of incoherent light.

FIG. 28: ***1991 International Symposium On Display Holography Participants*** **(1991) by Steven Smith**

The last two reflection holograms are on the shorter walls, next to each door. Adjacent to the holographic stereogram of the symposium participants is a white light reflection hologram of a lion made by NIKFI, the Cinema and Photo Research Institute in Moscow, Russia, around 1976.[22] Most of the holograms in the gallery came without frames, so we chose to frame them modestly, with thin, plain, black frames. However, the lion came to us in its original extravagant gold frame. So, we chose not to reframe it, for the sake of authenticity to the presentation that the NIKFI holographers' initially intended.

This holograms has a relatively steep reference angle; while most holograms have a reference angle near 45 degrees from the direction perpendicular to their surface, this hologram has a reference angle of 27 degrees. The steepness of this angle has always made the image of the lion difficult for us to view in the past, because it's difficult to get the spotlight far enough away from the hologram. However, we were able to illuminate it successfully using the lighting tracks in the gallery. In retrospect, though, this hologram may have been intended to be displayed sitting at an angle on a pedestal with its top edge resting against the wall behind it—a method that Bjelkhagen mentioned to us during his visit. This alternative presentation would allow us to place the light much closer to the hologram, in case it needed to fit into a narrower space.

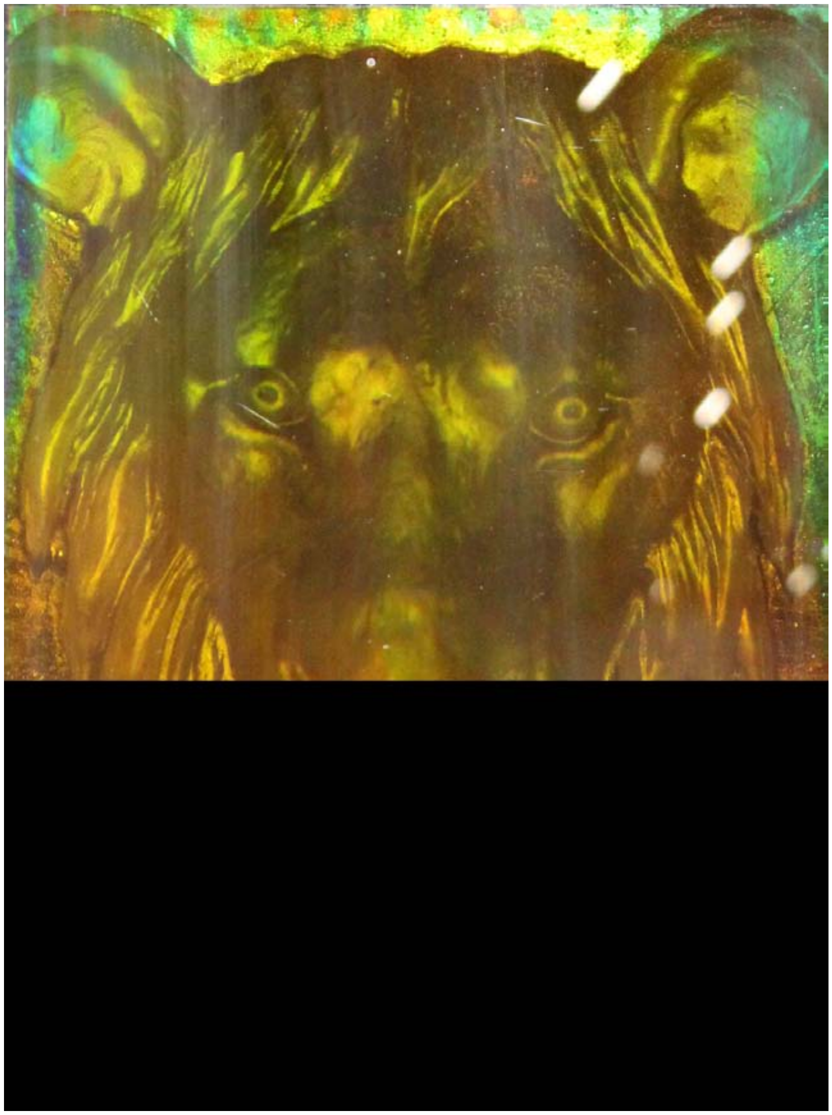

FIG. 29: ***Lion*** **(1976) by NIKFI**

The final, twentieth white light reflection hologram is on the opposite wall, adjacent to the portrait of Jeong near the other door. It is a series of multicolor white light holograms, which look like stickers. Unfortunately, we know very little about them. Something like this is more likely to have been produced by a company rather than made by an ordinary holographic artist. Ed believes that it may have come from Japan. Unfortunately, the artist is unknown. Anyhow, these are excellent quality holograms which show a wide variety of the colors that can be recorded using true color methods of holography.

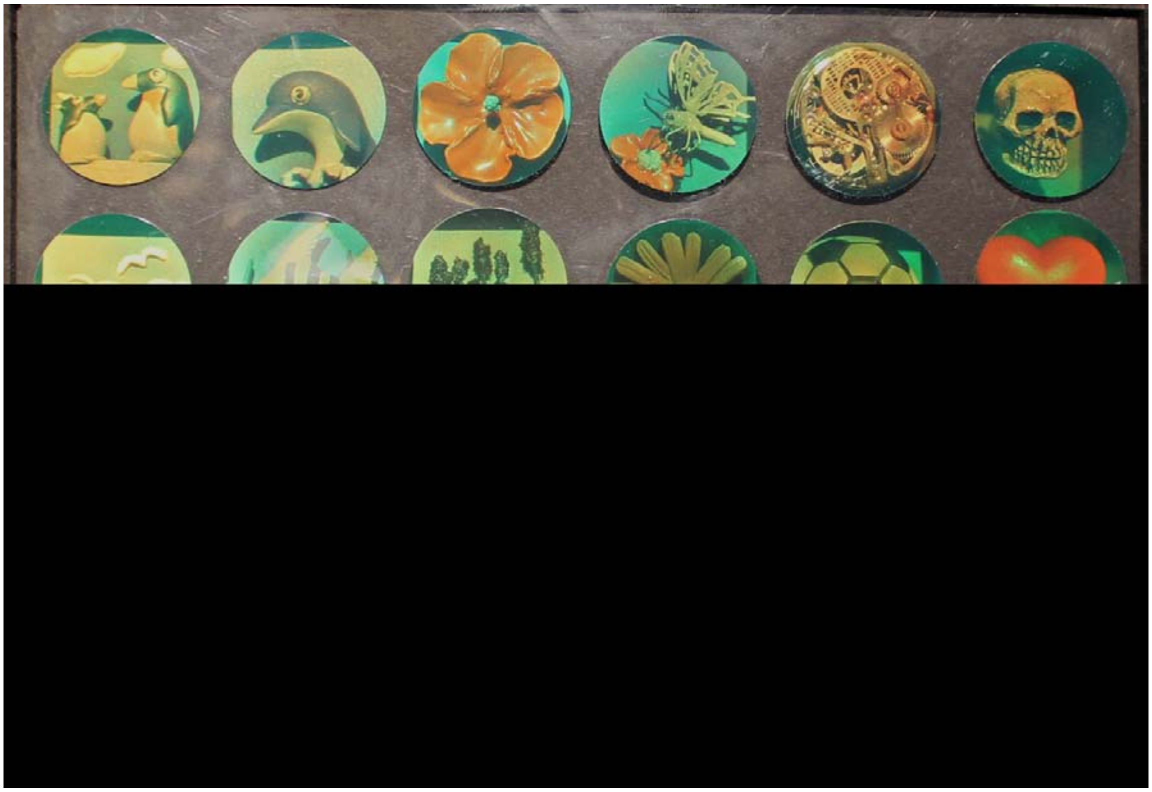

FIG. 30: *Untitled* (Unknown Year) by an Unknown Artist

In addition to these twenty white light reflection holograms, there are thirteen laser transmission holograms illuminated in the cabinets opposite the wall of reflection holograms. These include three pulsed holograms made by Jeong and Wesly at Fermilab, two portraits (one of Jeong, the other of Phillips) made at Lake Forest, and a number of other compelling holograms of objects or composed sculptural scenes. Unfortunately, I've been unable to identify the artists who made many of these transmission holograms.

Illumination of these transmission holograms required a lot of thought and planning, since each hologram must be illuminated at its own particular reference angle with a diode laser. After working (with much help around the department) to construct the thirteen necessary laser mounts, we removed the collumating lens from each diode laser, then soldered each into place and secured them in their mounts. I assigned a laser and mirror to each transmission hologram. Next, we powered all of the lasers and I aligned them each to reflect from a mirror and onto a hologram at the desired angle. I aimed to maximize the distance that each beam could travel, because the laserbeams widen as the light travels farther from the diode. This was in an attempt to maximize the area of the crosssection of each laserbeam, since this is the area that hits each hologram. These spots of light become our windows into the scene presented within each hologram, so we would like for them to be large enough to see through comfortably.

There is currently a cylindrical transmission hologram in a viewing apparatus inside one of the cabinets in the gallery. In the future, I hope to install a few more cylindrical holograms—it seems appropriate, since they were Jeong's invention. We have an impressive large cylindrical hologram that Jeong made of his children decades ago. We also have a number of small cylindrical holograms which accompany Jeong's papers, like *Cylindrical Holography and Some Proposed Applications* and *360° Holography*. Additionally, I'd also like to make a display of our best embossed holograms, and we have a large laser transmission hologram of a skeleton which is quite impressive, although a bit tricky to set up. We repeatedly considered the idea of keeping the skeleton in the closet. Perhaps the gallery will always be in a state of flux; it would be ideal to switch out the holograms on display periodically with other strong holograms, so that audience exposure does not stagnate. Anyhow, these are the next progressions that I envision in the gallery.

All in all, I tried to include a very technically strong but diverse selection of holograms in the gallery, in hopes of exposing audiences to the many possibilities that holography presents, and inspiring as many viewers as possible to learn more about holography. Spaces like this are critical in order to expose new audiences to holographic art. Diverse audience exposure is absolutely necessary for the success of holography as a medium.

IV. EXPERIMENTATION AND PRODUCTION

A. Apparatus

Essentially, when making a successful hologram, a laser beam is split into two parts: the reference beam and the object beam.[3] The reference beam is directed to illuminate the film surface directly, while the object beam is directed to illuminate the holographic object. This light then scatters from the object to the film surface, where the film records the interference pattern of these two beams. The intensity ratio of one to the other is important, and should be measured by a light meter, then balanced (at least roughly) through experiment.[3]

When making holograms, the environment must be vibration-free. Even very slight movement is dramatic, considering the scale of the optical wavelengths which we're working to record. Any movement between the holographic object and film can cause distinct, dark fringes to appear in the holographic images. These may darken the hologram so much as to completely destroy the image, leaving nothing to view.

We took a couple of precautions in an attempt to avoid these issues. First, we "floated" the optical table (Model: Newport Corporation NRC Pneumatic Isolation Mount Type XL-A) on a cushion of air in the bladders of the table's legs in order to isolate it from movements of the floor. (If an optical table is unattainable, Jeong demonstrated that a sandbox can be used as an alternative.) Second, we covered the table with Styrofoam (which we first painted black) to minimize air currents around our optical equipment. Third, we aimed to minimize exposure times, hoping to consequently minimize the amount of time that the objects or film have to shift around. Short exposure times require either a very powerful laser or highly sensitive film.

We have an eighteen milliwatt JDSU (model 1145P-3600) red Helium-Neon laser with a Coherent power supply. While this laser is not nearly powerful enough to do pulsed holography, it certainly has enough power to make traditional laser transmission and white light reflection holograms using our PFG-01 and PFG-03M holographic high resolution photographic plates. This laser provides us with spatially and temporally coherent light. This is necessary, because if incoherent light is present, it can ruin the hologram. The light is focused in a narrow, steady beam of a single wavelength: near 633 nanometers.

There are all sorts of optical instruments which can be helpful when making holograms.[1] One example is a beam splitter: a partially reflective piece of glass used to reflect a part of an incident beam and transmit the rest. A beam splitter can be used to divide the beam from the laser into the reference beam and the object beam. Spreading lenses can increase the cross-sectional area of a narrow beam so that the film and object can be fully illuminated. Front surface mirrors and apertures are often used to direct beams. A film holder can be used to ensure that the holographic film doesn't move during the exposure process, which is helpful for eliminating unwanted dark fringes from the image. A shutter is needed to block light from reaching the film before and after the exposure time. Many of these tools are optional or substitutable, so I'll describe our particular experimental apparatus.

B. White Light Reflection Hologram

Our first objective was to create a single beam white light reflection hologram. To do so, we sent the laser beam through a spatial filter to help ensure that the light is spatially coherent. Next, we used an aperture with a diameter of about seven millimeters to get rid of stray light around the object and film. The beam was then reflected off of a large front surface mirror and onto a spot on the optical table. We took note of the location of the spot, using a light meter to measure the power of each beam (the reference beam and the object beam).

After determining that the beams' power ratio is reasonable, and calculating the proper exposure time for our hologram considering our particular laser and the sensitivity of our film, we close the shutter and position our object on the table where the spot of light from the laser beam was located. That object must be mechanically stable in order for the interference pattern of the object and reference beams to be properly recorded. After securing it, we must turn off the room lights and turn on our green safe-lights. We used green lights because green wavelengths shouldn't damage our red-sensitive holographic film. Then, we placed the light sensitive plate in a sturdy location with the emulsion-covered side toward the object (we simply placed the plate directly onto our object). We lined our black Styrofoam around the edges of the table to try to minimize air currents, and then waited a few seconds for any lingering vibrations to fully dampen before opening the shutter to expose the film.

After the proper exposure time had elapsed, the shutter closed, and we began to develop the hologram. First, with the room lights still off, we rinsed it in cold water for two minutes. Next, we mixed the developer; it's composed of a mixture of equal parts

JD-4a and JD-4b holographic film formulas, which must be between seventeen and nineteen degrees Celsius when the hologram is submerged. We placed the plate into the developer and gently agitated it for two more minutes. Afterwards, we rinsed in cold water for another two minutes, and then submerged the plate in re-halogenating bleach for about two more minutes, agitating it periodically. At this point in the developing process, the plate is no longer light-sensitive. We then rinsed the hologram in cold water once again, this time for five minutes. After this final rinse, the plate can be run through a series of denatured alcohol and water solutions which get progressively stronger (first 50:50, then 70:30, and finally 100 percent denatured alcohol) to speed up the drying process.

After a hologram has dried, we should be able to view it with a point source of white light (we used one of the extra spotlights from the gallery) illuminating it from the proper reference angle. Unfortunately, we haven't had great success yet. We've speculated that this is due to slight vibrations of our objects which destroying the interference pattern needed to form a hologram. We aim to get rid of these vibrations by using more stable mounts for our film and object.

C. Laser Transmission Hologram

[insert text]

[insert figure]

V. CONCLUSION

Decades ago, when the public was first introduced to holography, they predicted that it was the medium of the future. They recognized its potential and allure. However, it was nearly left in the dust. Increased audience accessibility is a major piece of what led to progress in holography during the first holographic renaissance. Along the same lines, I believe that spaces like our holography gallery are critical if holography is to progress in the future. Given the vast and conceptually rich artistic potential which clearly lies within holography (given all of the examples in the gallery), it seems to be a medium worth pursuing. My objective for the holography gallery is to provide a space for scientific and artistic audiences to blend and be exposed to the possibilities that holography holds. Perhaps this could be one step toward a second holographic revival.

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