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

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Abstract
A hologram is a complex diffraction grating made by recording the interference pattern of two electromagnetic radiation fields on a light-sensitive surface. Holography is the study of this process. While holograms have been used for many purposes, I will 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 get almost no exposure today, but it seems that their aesthetically striking nature cannot be ignored by 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 a "holographic renaissance," especially considering the changes in artists' and audiences' mindsets and expectations over the time that holography has lain somewhat dormant. My objective for this gallery is to provide a space where this exposure can occur.

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LAKE FOREST COLLEGE

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

by

Zoe DeRouen Darlington

May 1, 2019

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 electromagnetic radiation fields on a light-sensitive surface. Holography is the study of this process. While holograms have been used for many purposes, I will 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 get almost no exposure today, but it seems that their aesthetically striking nature cannot be ignored by 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 a "holographic renaissance," especially considering the changes in artists' and audiences' mindsets and expectations over the time that holography has lain somewhat dormant. My objective for this gallery is to provide a space where this exposure can occur.

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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 complicated 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 is 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.

Dennis Gabor introduced the basic concepts involved in holographic imaging in the 1948, in an attempt to improve the resolution of an electron microscope. The ideas remained somewhat dormant, however, until the 1960's. Then, Holography experienced a sort of reawakening, 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, which make up visible light. In particular, we will 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 are mutually coherent. While the concepts we will discuss can be applied to any coherent waves, we will 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 will consider the geometric model, a physical model to help holographers visualize what happens during their work in the laboratory. The geometric model is a highly visual description, generally more accessible to the artist, non-scientist, beginner than, say, the Fourier Transform 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. 1.1.1. 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. If we imagine that the wave is propagating, then the number of wavelengths that pass some point every second is called the wave's frequency.

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. 1.1.2 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. 1.1.2 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.

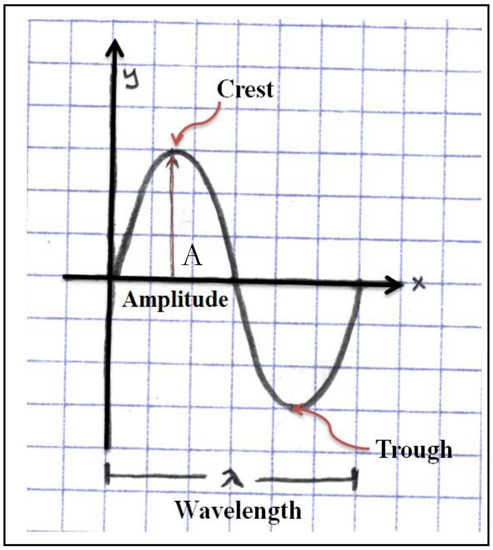

FIG. 1.1.1: Sinusoidal wave with amplitude A and wavelength λ

In 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. 1.1.3. 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.

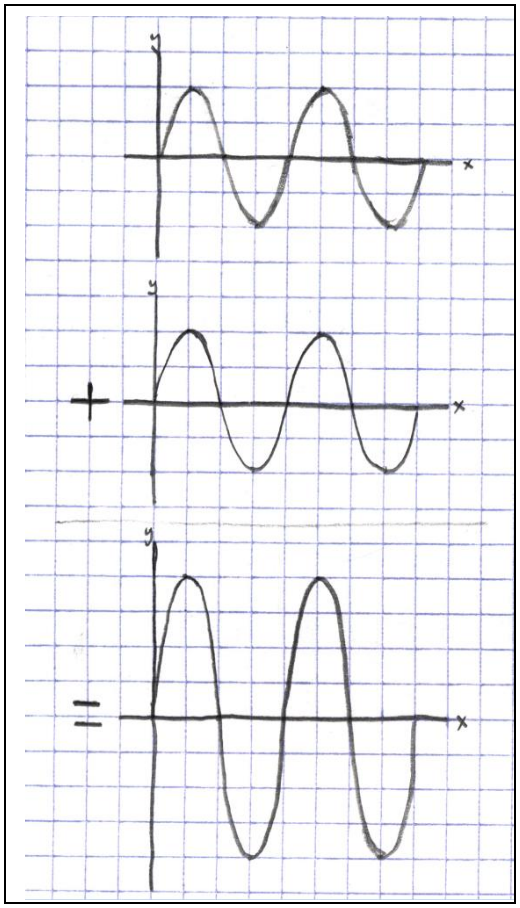

FIG. 1.1.2: Constructive interference of two sinusoidal waves with the same frequency and phase

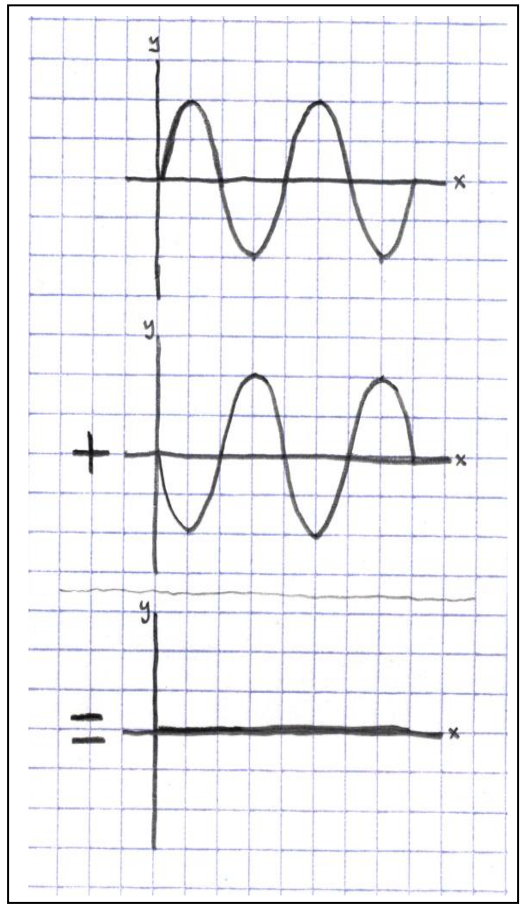

FIG. 1.1.3: Destructive interference of two sinusoidal waves with the same frequency, but 180 degrees out of phase

Thus far, we have considered some of the simplest cases. Notably, white light and ambient light are generally made up of a multitude of waves with many different wavelengths, 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 do not 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 do not 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. 1.2.1. 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.

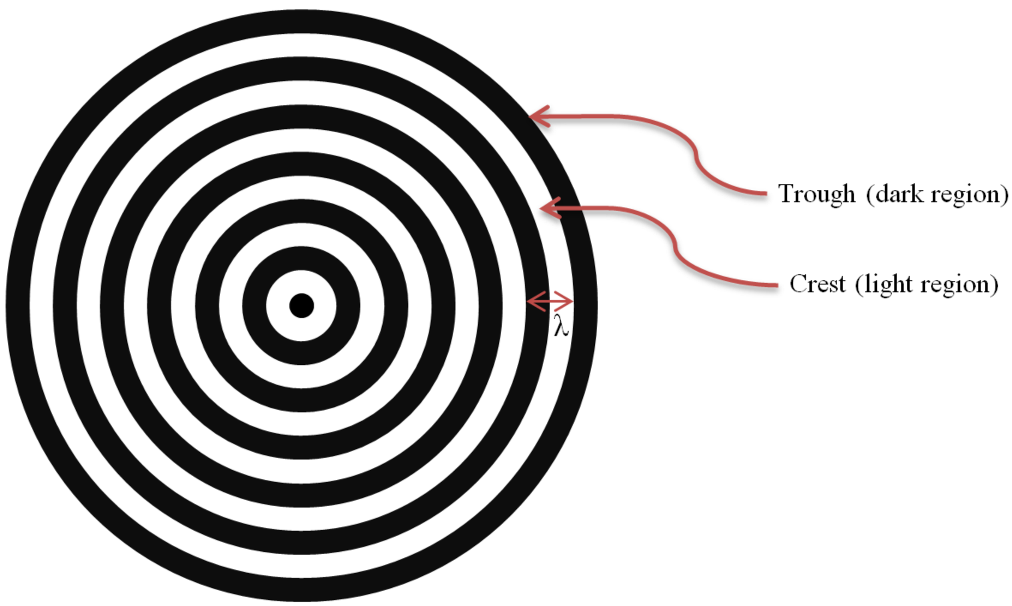

FIG. 1.2.1: Cross-sectional view of spherical wave fronts radiating at a constant frequency from point at the center

Similar to before, we can "add" these waves. This time, we will 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. 1.2.2.

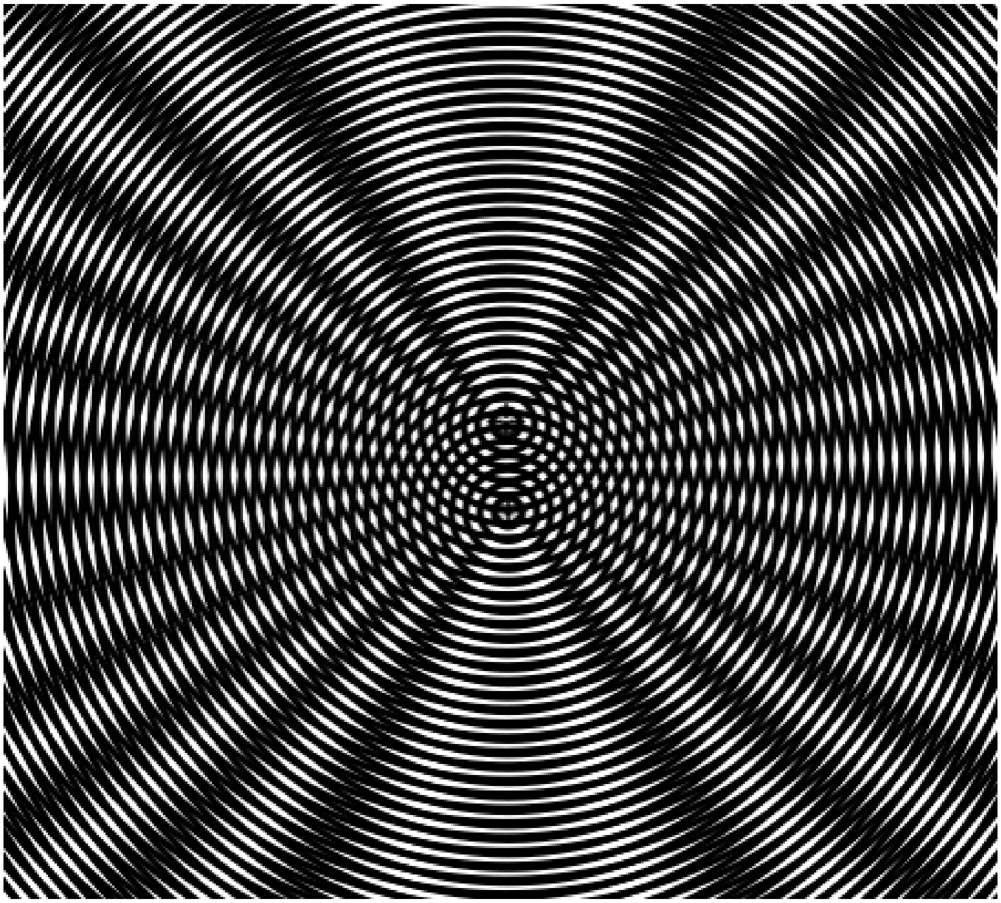

FIG. 1.2.2: Moiré pattern created by the superposition of two identical sets of concentric circles, representing spherical waves radiating from two points, in this case.[5]

While Fig. 1.2.2 gives a very clear diagrammatic example, real world examples can be found as well, like in the ripples of a puddle (see Fig. 1.2.3).

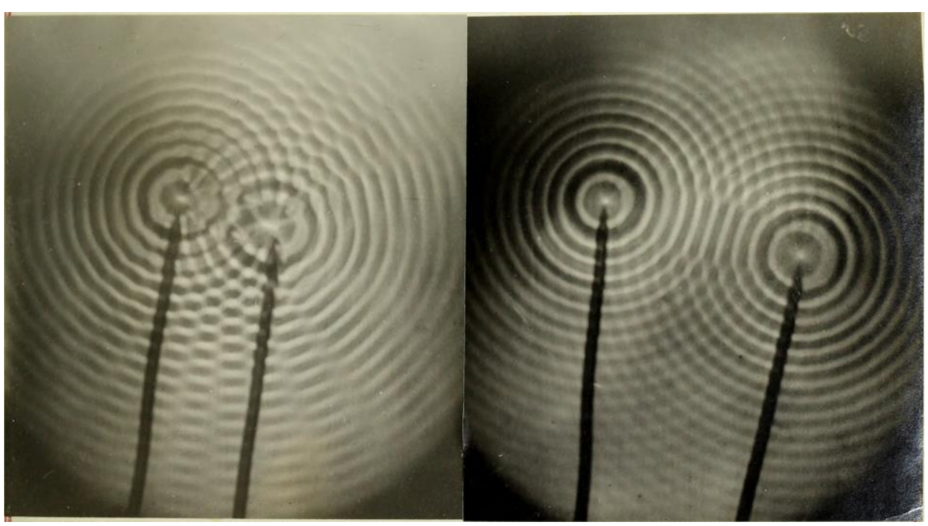

FIG. 1.2.3: Interference of ripples (small waves) of water from two sources of continuous waves emitted at a constant frequency.[6]

If we trace along all of the light regions where there is constructive interference in any given interference pattern like these, we will get a series of hyperbolas.[2] This is demonstrated in Fig. 1.2.4.

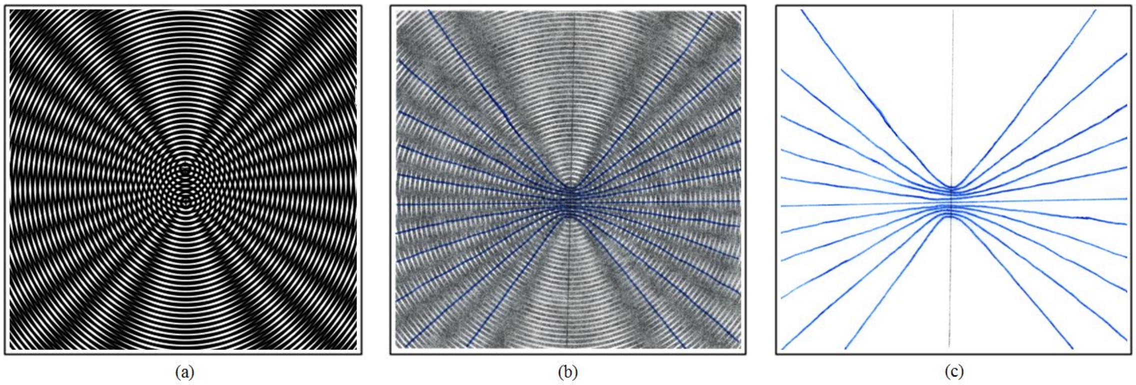

FIG. 1.2.4: Finding the set of hyperbolas associated with Fig. 1.2.2 (repeated in part (a)) by tracing the regions of constructive interference. Part (b) shows the traced lines on top of the original interference pattern. In part (c), the interference pattern was removed, leaving only the family of

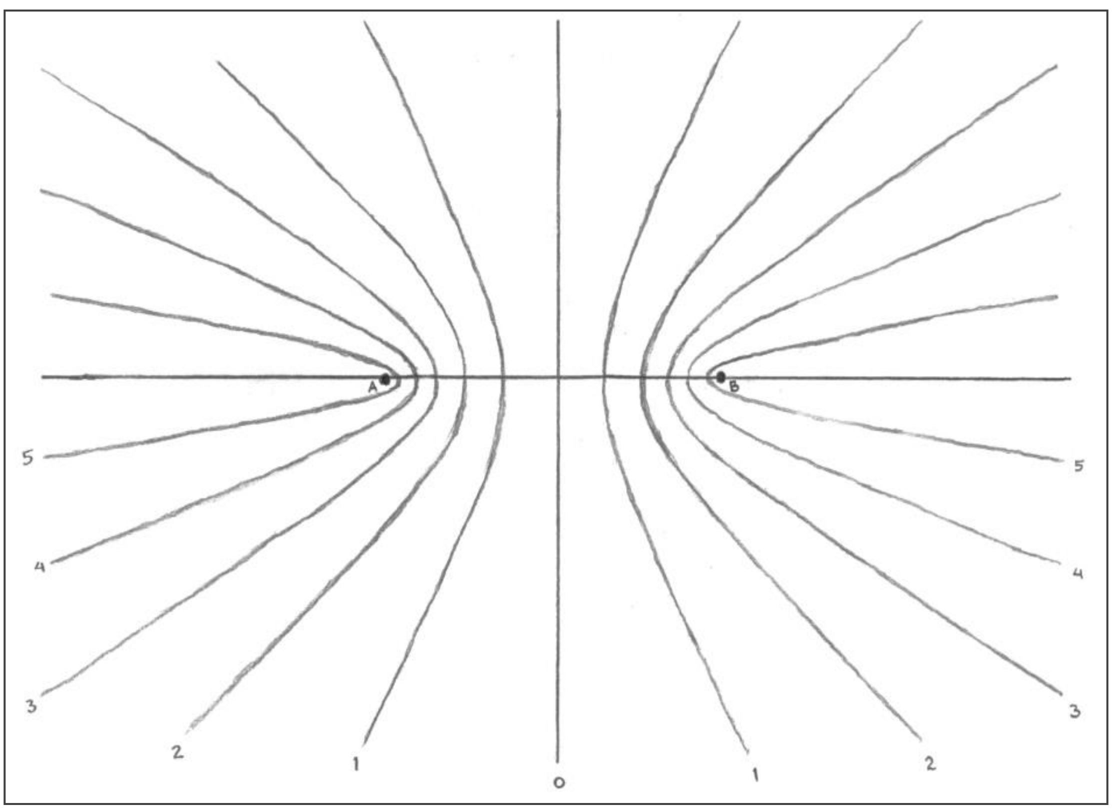

FIG. 1.2.5: Family of five hyperbolas associated with the interference of coherent waves from sources at points A and B.

I have enlarged another set of hyperbolas like those shown in Fig. 1.2.4 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. 1.2.5.

Imagine that the zeroth order line—the straight, vertical line, exactly in the center of the two foci A and B—is a partially reflective mirror facing point A. When light hits this surface, some will be transmitted, and the rest will be reflected. In optics, the Law of Reflection states that when a light ray is reflected, the angle of incidence is equal to the angle of reflection, where the angles are measured from an axis perpendicular to the reflective surface. Fig. 1.2.6 acts as an example which shows three incident light rays (in red) from source A, but actually they radiate from A in all directions. Rays of light will be reflected as shown in Fig. 1.2.6 (the reflected rays are depicted in pink).

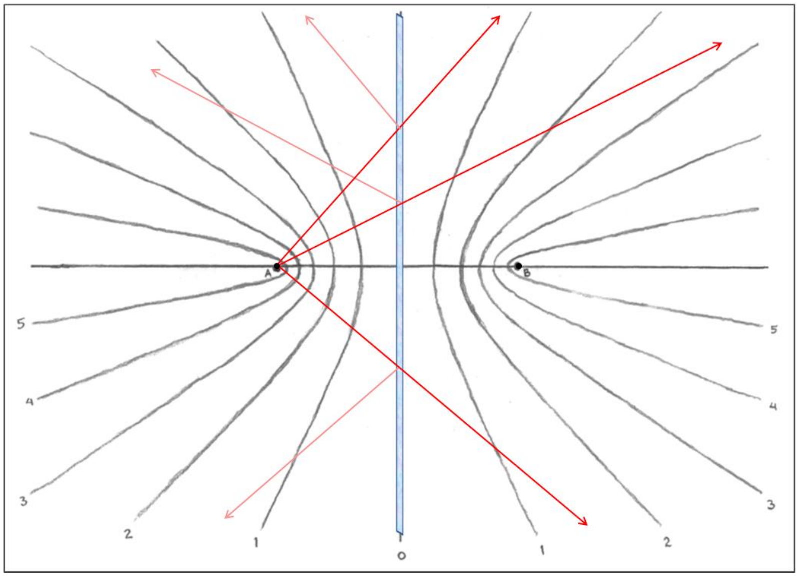

FIG. 1.2.6: Rays from A reflected from a mirror at the zeroth order line

When rays of light converge, an image is formed. The reflected rays in Fig. 1.2.6 are pointing away from each other, so it is clear that they will not actually converge. Thus, there will not be a “real image.” However, if we extend the reflected rays backward on our diagram, then we can find the point at which they appear to converge. At that point, a "virtual image" will appear. Fig. 1.2.7 shows that when these light rays are extended as described (shown with pink dotted lines), they appear to converge at point B. So, when light from source A is reflected from the plane mirror at the location of the zeroth order line, a virtual image of source A appears at the location of source B. Thus, 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]

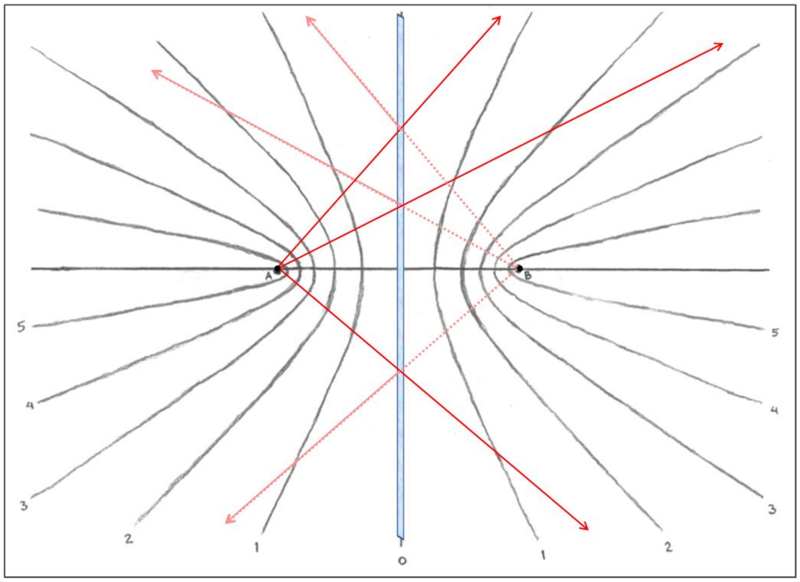

FIG. 1.2.7: Reflected rays from Fig. 1.2.6 extended to find the location of the virtual image

Next, imagine Fig. 1.2.5 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 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] This is illustrated in Fig. 1.2.8, which shows how one ray from A is reflected and transmitted at each hyperbolic mirror encountered. 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 have described for our simple case still hold.

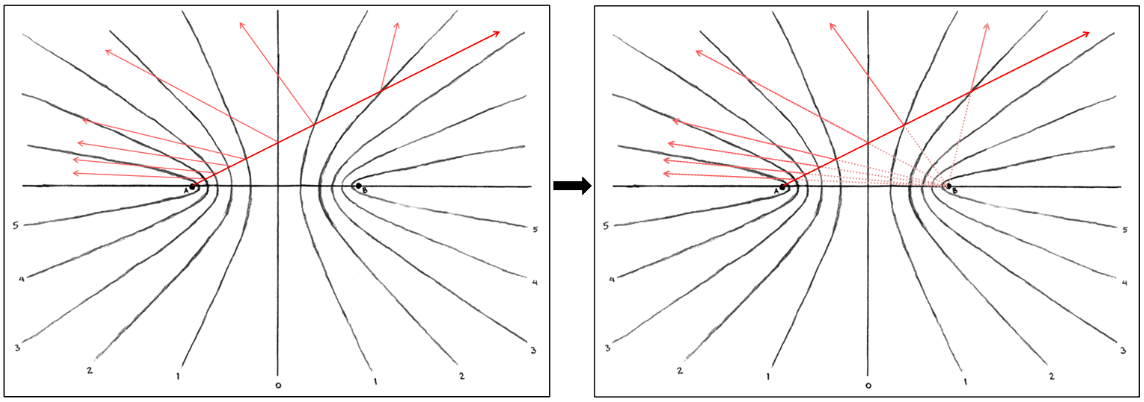

FIG. 1.2.8: Rays reflected from each partially-transmitting hyperbolic surface, extended to locate the virtual image at B. Similar to Fig. 1.2.6 and Fig. 1.2.7.

Assume that we now place our light-sensitive holographic plate somewhere in this region. Light coming directly from the laser to the plate (the reference beam) will interfere with light reflected from the object (the object beam), and the interference pattern created at the location of the plate will be recorded. We must recall that the coat of light-sensitive emulsion on our plate has some thickness which is substantial relative to the width of a wavelength of light (visible light has wavelengths hundreds of 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] Now we can conceptualize that the volume of the light-sensitive emulsion coating the glass (or plastic film) 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 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 visual reconstructions of 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 Transform Model

Successful, impressive holograms can be created by individuals without a mathematical or scientific background, but 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 will not find a technical, mathematical description very beneficial, so I will not go into detail here. I have mentioned the Fourier transform model so that those who are interested in gaining more insight into the mathematics of holography will know where to begin their research.

III. HISTORY

A. Origin

Dennis Gabor led the way in holography by presenting the basic concepts in 1948 in an attempt to improve the resolving power of an electron microscope.[2] While the electron microscope had significantly more resolving power than an ordinary microscope, spherical aberrations of magnetic electron lenses still presented problems which Gabor sought to overcome.[2] His solution was to use the microscope to record the entirety of the optical information available: both the amplitude and phase of the light.[7] Given that information, the aberrations could be corrected later. He called his technique "wave-front reconstruction."[8]

This technique required coherent light, which was fairly difficult to work with at this point in time (the laser, a practical source of coherent light today, had not been invented yet). Gabor used a mercury lamp with a narrow-band green filter, which was approximately coherent for short distances, to create the first hologram, which depicted the names "Huygens," "Young," and "Fresnel," (three important physicists in the field of optics) in opaque letters on a clear background.[8] Since the light from the mercury lamp was not highly coherent, the

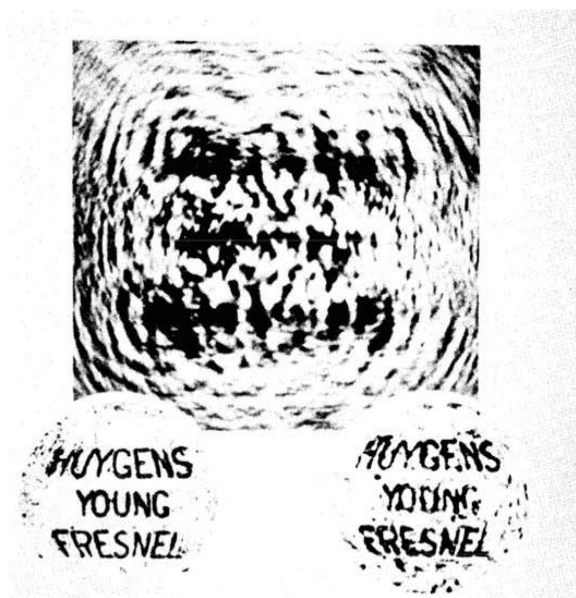

FIG. 2.1.1: The first hologram, made by Dennis Gabor in 1948 (depicted here highly magnified)[8]

hologram had to be very small: it was less than two millimeters in diameter.[8] While Gabor's ideas were groundbreaking, it was difficult to fully appreciate them when they were presented on such a miniscule scale.

B. First Revival

After going fairly unnoticed for about fifteen years, Gabor's work in holography began to generate new interest in the 1960's. The invention of the laser in the early 1960s helped to pave the way for a holographic "renaissance,"[2] 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.[9] 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 could not 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.[10]

C. Place in Art History

Artists became interested in holography as an artistic medium in the early 1970's.[10] 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.[10] 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,"[10] as argued by Emmett Leith, an influential holographer during the first holographic revival.

1. Digital and Technologically-Based Media

Display holography has been defined as "the recording and reproduction of three dimensional images on a flat film surface for the sole purpose of viewing."[11] While this is similar to the way that other art media like painting and photography are defined, holography's ability to present a truly three-dimensional image, without flattening it into the two-dimensional viewing medium, is unique. 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,"[10] an appeal to the public, tempting them with what is familiar. Holography has also been referred to as "laser photography."[9] 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. For example, 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.[11] It is useful to use a light meter to help determine proper exposure settings in both fields. Additionally, holographic film is chemically developed like photographic film.[11] In both holography and darkroom photography, the film is developed, stopped, fixed, and washed.[11]

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.[11] 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).[11] Additionally, there is no negative in holography comparable to a photographic negative. Holography does not use a camera, and there is no lens between the object and the film. This is because to properly record the interference pattern, "...every point on the film must receive light information from every part of the object."[11] A lens would prevent this by focusing the light to one point on the film. Thus, a hologram can record a longer depth of field in high resolution than a photograph is capable of recording.

When we take a photograph, we record information about the amplitude of the light reflecting off of the objects within that photo.[7] Then, when we look at that photograph, light is reflected off the photograph and into our eyes. Thus, we are given information about the amplitude of that light which once irradiated from the photographed object. Photographs cannot tell us anything about the phase of that light, though.[11] 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.[7] 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."[7]

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 are 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* (1992) or Joseph Burns and Serge Honinow's *Nested Arrays* (1981), currently on display in the gallery).

While holograms do not 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 separate the viewer from our usual physical environment. Holograms, however, do not 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 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.

2. Place in the Contemporary Art World

The following quote was published in Mike Edelhart's *3D TV is Coming*, TV Guide: A Reprint from December 15, 1973.

> Through the work of Jeong and Francisco, a science-fiction dream, 3-D TV, has been moved well out of the realm of fantasy. Even a few years ago, three-dimensional television was considered a teen-age pipe dream by most scientists. Today, it is considered not only possible but inevitable and sooner than you think.[9]

In Edelhart's *3D TV is Coming*, Jeong predicted that the public would have access to many holograms by the mid 1980's.[9] He recognized the aesthetic impact that holograms can have, and saw holography's potential for a significant future in the art world. He imagined large holographic displays in public places.[9] Also, he predicted that holograms would be brought into homes through "3D TV," "[holographic] cassettes, and daily newspaper holograms."[9] The tone which seems to permeate most literature on holography is one of hope and imagination—one which sees holograms as a medium of the future, like something out of a science fiction novel.

Evidently, these hypotheses were faulty. Holograms are almost absent from the contemporary sphere in any of its many capacities. So, why do we not see contemporary artists picking up the medium? I think it is important to consider the original context of holography, and think about the audiences who would have been there decades ago, when it was first being presented. Holography, like many digital or technologically based media, does not fit into the category of "fine art," the way that it is traditionally defined. In an essay by Po-Hsien Li, they discuss "the five 'major arts' of painting, sculpture, architecture, music, and poetry" that were seen as the superior art forms since this conception took shape around the 18th century.[12] Decades ago, during the emergence of holography in the art world, there was still "...great resistance to technology-based art forms," when considering "fine art."[12] Alternative art media (like photography, video, film, computer-based artwork, and, of course, holography) were treated with hesitance and a lack of valuation relative to their "fine art" counterparts. Also, these media were often displayed separately from more traditional media, like drawing, painting, and sculpture.[13] This may have contributed to the decline of the medium, or perhaps it can help to explain why more artists did not choose to begin working with holography.

The divisions between "fine art" and less-valued art permeated the minds of artists decades ago, thereby gaining meaning. However, my experiences as an artist, interacting with other young artists and viewing their work, have suggested to me that these traditional categories have lost much of their meaning. Barilleaux argued that "if art holography is to gain recognition within established art circles, it is imperative that artists who make holograms see themselves within the context of the constantly changing visual fabric of our culture."[13] Along these lines, it is notable that most young artists who I have encountered do not make value judgements about artwork based solely on this distinction between. Thus, I do not think that this initial barrier would stifle the productivity of the medium if it were properly reintroduced today.

Notably, though, holography has not evolved and permeated contemporary art even to the degree that other technologically-based art forms (like film, video, photography, etc.) have. A few factors have led to this state. For one, it is fairly difficult to make holograms. Most people who know a bit about holography believe that it takes a lot of niche, often expensive equipment, in addition to skill (both artistic and technical) in order to create successful holograms. In general, the equipment is not easily accessible.

Another reason why Jeong is such an admirable figure in the holographic community is that he worked to increase accessibility by providing simple, low-cost alternatives and tips, and writing clear, informative literature on holography. For example, in the abstract of his paper, "Simple holography," he stated, "the procedures we propose herein are as simple as it is physically possible. In the process, we have made holography not only as simple as possible, but safer, less expensive, and more accessible to young people."[14]

Additionally, many of the artists I have encountered are not interested in working to the degree of precision required to create holograms. Much of the time in the field of display holography, an artist will work with a holographer "who serves primarily as a technician, and sometimes the artist does little more than convert a pre-existing idea or image into a three-dimensional illusion."[13] While it is exciting that this process creates new visually and conceptually interesting holograms, and involves interdisciplinary cooperation between scientists and artists, it is unfortunate that this does not necessarily show the unique capabilities of the medium. Perhaps if there were more artists working to understand and utilize the qualities unique to holography (and then exposing their work publicly, of course), then more interest in the field would be generated.

Holograms are also fairly difficult to display, as my work assembling the gallery has made clear. Each hologram requires its own particular lighting. The type of light used, and the angle at which it hits the hologram make all the difference between a stunning holographic display and an underwhelming sheet of glass with its image completely hidden. Holograms also tend to demand a dark environment, so that they are not drowned out by all of the brightness surrounding them. This helps to explain why we do not see more holography on display in either public or private spaces today, contrasting Jeong's predictions.

On another note, there is not a lot of readily accessible information for individuals who might be interested in holography today. Holography has much less written documentation than traditional media or even other technologically based or digital media.[13] Also, relative to work in these other media, there is not a lot of good holographic work available for exhibition.[13] The work that is shown is often made by artists who have established careers working primarily with other media.[13] Barilleaux argued that this does not give a fair portrayal of holography as its own art form,[13] and I must agree.

Lack of knowledge about holography in the art world, the science world, and general public contributes to the lack of productivity in the medium. Barilleaux recognized some steps which he believes need to be taken before we can see progress in the holographic community.[13] The first is “the recognition by the holography community of the complex structure of the art world—a system with which they should become familiar if not part of.”[13] Second is “the education of scholars, curators, critics and dealers about the field of holography and the work of artists making holograms.”[13] Third, “most importantly, the creation of meaningful works of art using holography.”[13] Given the location of our holography gallery (in the center of a science building, a traditionally atypical place to view art), and the exposure that it provides to this broad array of artistic successes in the field of holography, I believe that I have worked toward Barilleaux’s first and second goals through curation of the gallery. I hoped to make more progress toward the third goal during my work over the past few months, but my interest and efforts will certainly not end with this project. I aim to make myself an active participant in the creation of display holograms in the future.

D. Place at Lake Forest College

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 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!”[15]

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.[16] With the workshops and symposium, Jeong helped to bridge the gap between holographic scientists and holographic artists.[10]

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 have 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-five-foot hallway within the physics department, which we transformed into a gallery for display holography. 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 allowed us to power diode lasers. We used them to 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

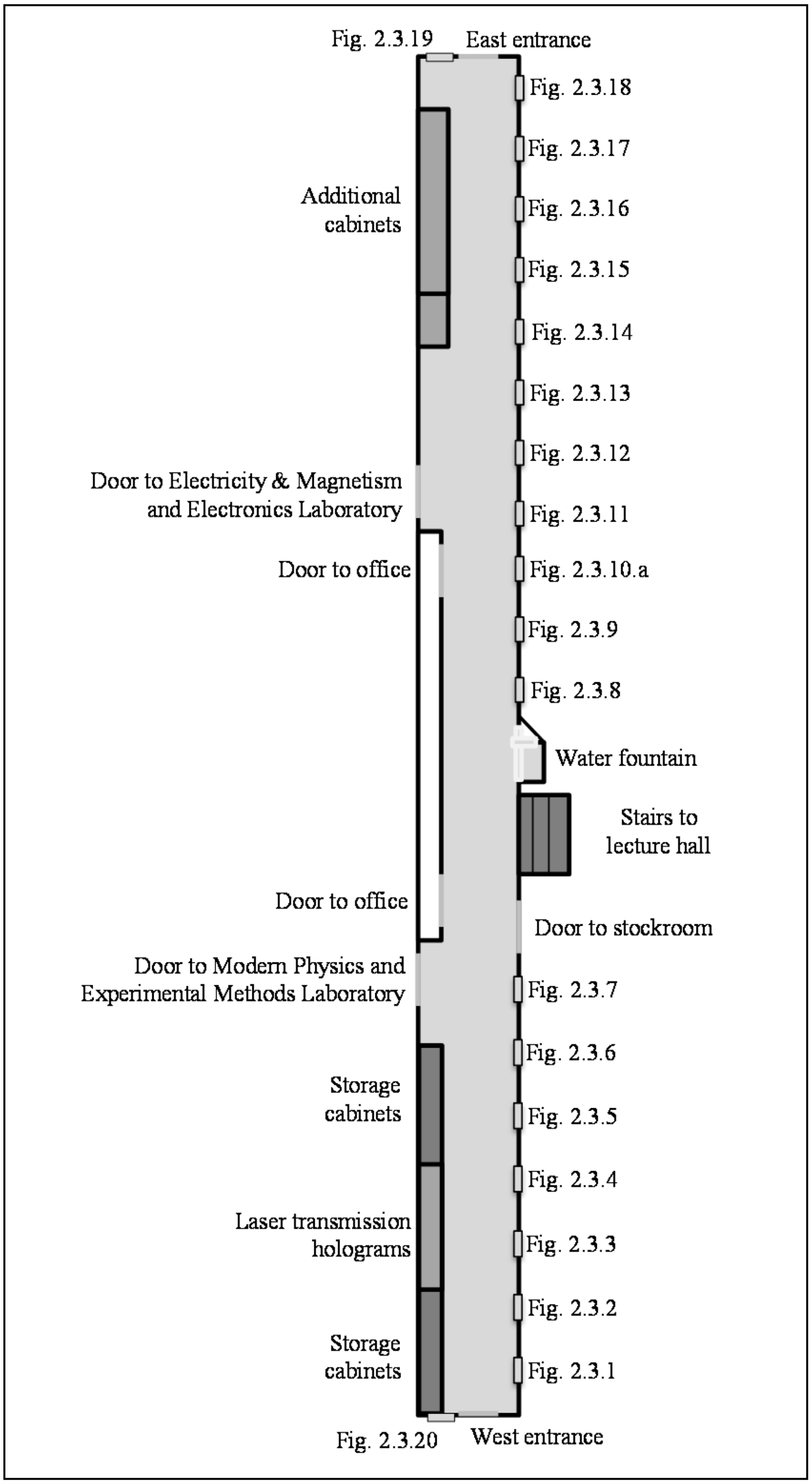

FIG. 2.2.1: Blueprint of gallery space.

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.

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. Wesly 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 Chamber 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. I photographed each of the reflection holograms, with the exception of Lon Moore's *Saturn* (1978) and Jonathan Collins and Pascal Gauchet's *Alice in Wonderland I* (1984) (I found those two photographs elsewhere). The following figures show these photographs. Of course, these photographs cannot convey the striking characteristics unique to holography displayed by each work—each presents a fixed view of a hologram, compressing the image of each object into two dimensions. Nevertheless, the photographs do represent one possible view of each hologram.

We framed each hologram (unless already in its original frame from the artist, to respect their intentions) in a thin, black, metal frame, and matted those of the reflection holograms which we felt needed mats, based on size and placement of the composition on the film or glass plate. While some of these holograms may have been originally perceived more as scientific objects resulting from optical experimentation than as works of art, this framing process fixed the role of each hologram as an art object.

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 (my eye level, 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 are pictured in the order that they appear on the wall when the gallery is entered from the west side. This west wall, before the doors creating a division near the center of the gallery, is primarily devoted to figuration, which is relatively uncommon in the field of holography. The first hologram displayed is a portrait of Dr. T. H. Jeong, made by the Holicon Corporation in Evanston, Illinois around 1988. It is 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 am 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 will 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, it is evident 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.)

According to Wesly, Holicon used a JK pulsed ruby laser. This laser's beam delivers a maximum power of 50 megawatts—almost three billion times more powerful than our 18 milliwatt Helium-Neon laser. Thus, exposure times can be quite short when using this ruby laser. In pulsed holography, the exposure time is only as long as the pulse emitted from the laser. The pulse of a JK pulsed ruby laser is only 20 nanoseconds long, in which time it delivers one joule of energy.

FIG. 2.3.1: ***Portrait of T. H. Jeong*** **(1988) by the Holicon Corporation. Lake Forest College Hologram Collection.**

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 was 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.

Everything in the original laser transmission master copy of this hologram would have appeared behind the plane of the glass, because when making a transmission hologram, the holographic plate is placed right on top of the object (or, in this case, right in front of Boy George's face). During the process of making a white light reflection copy, another photographic plate (which becomes the reflection hologram) can be placed against the laser transmission hologram, so that the image of the transmission hologram becomes the object of the reflection hologram. The result is a pseudoscopic image which appears to come out of the plane of the white light reflection copy.

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 holographic 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 is resting his chin on his fists, exposing the pattern of black dots covering the backs of his hands.[17] This one is in the Jonathan Ross Hologram Collection.[17]

The third hologram in the series is a wider shot including Boy George's shoulders. He was wearing a spotted scarf and hat, in addition to the rest of the harlequin look.[17] Large orchids were placed next to his head in this composition.[17] 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.

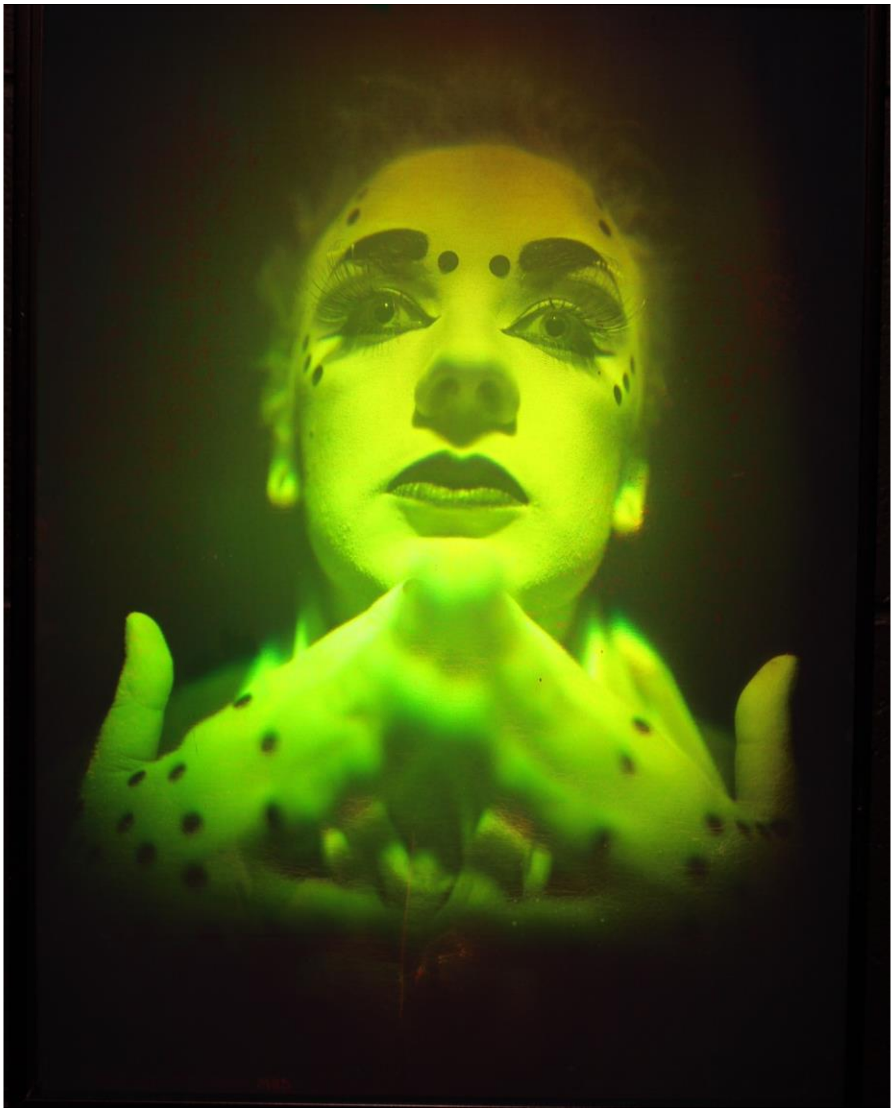

FIG. 2.3.2: *Boy George* (1985) by Edwina Orr and Richmond Holographic Studios. Lake Forest College Hologram Collection.

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 Olson in

1992. It is titled *Kim Budil*.[18] It is a somewhat abstracted nude, in which the model is sitting with her arms wrapped around her folded legs. Initially, Wesly 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 have found say otherwise.[18]

The Olsons used a green pulsed laser for their work, according to Wesly. This type of laser is, in some ways, preferred for portraiture and figuration, because it does not result in the waxy-looking skin textures that are typical when using a pulsed ruby laser, like the one used to create the aforementioned portrait of Jeong.

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 on texture and form within the composition perhaps more 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.

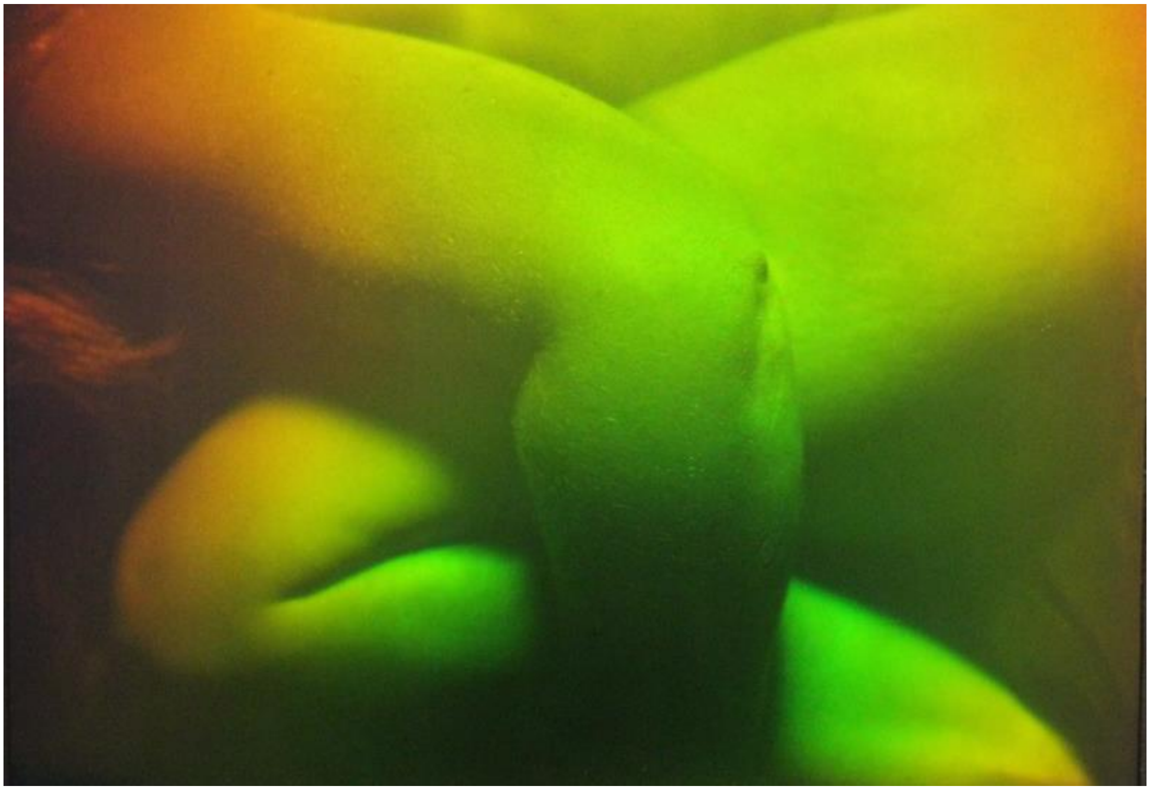

FIG. 2.3.3: *Kim Budil* (1992) by Bernadette and Ron Olson. Lake Forest College Hologram Collection.

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.[19] (Actually, it appears that this composition can still be ordered from Geola’s website today.)[19] *Your Beer Companion* is an animated, digitally printed hologram which Geola calls an “i-Lumogram.”[19] In other words, it is a video capture that was digitally turned into a hologram. This is similar to a stereogram (which I will describe soon).

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).

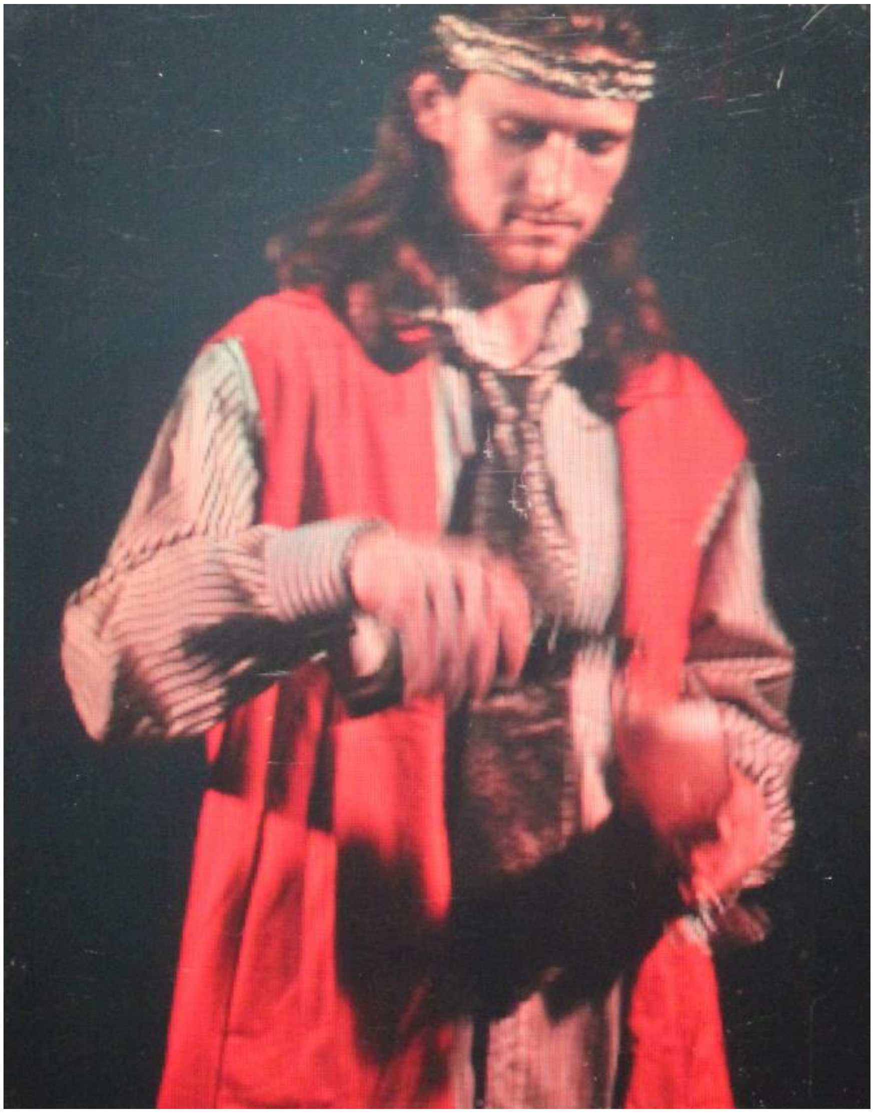

FIG. 2.3.4: *Your beer companion* (2002) by Geola. Lake Forest College Hologram Collection.

The fifth hologram in the gallery is *Michael's Portrait*, made by John Perry in 1984.[20] 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 have seen holographed thusfar), the Perry did not 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. 2.3.5: *Michael's Portrait* (1984) by John Perry. Lake Forest College Hologram Collection.

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.

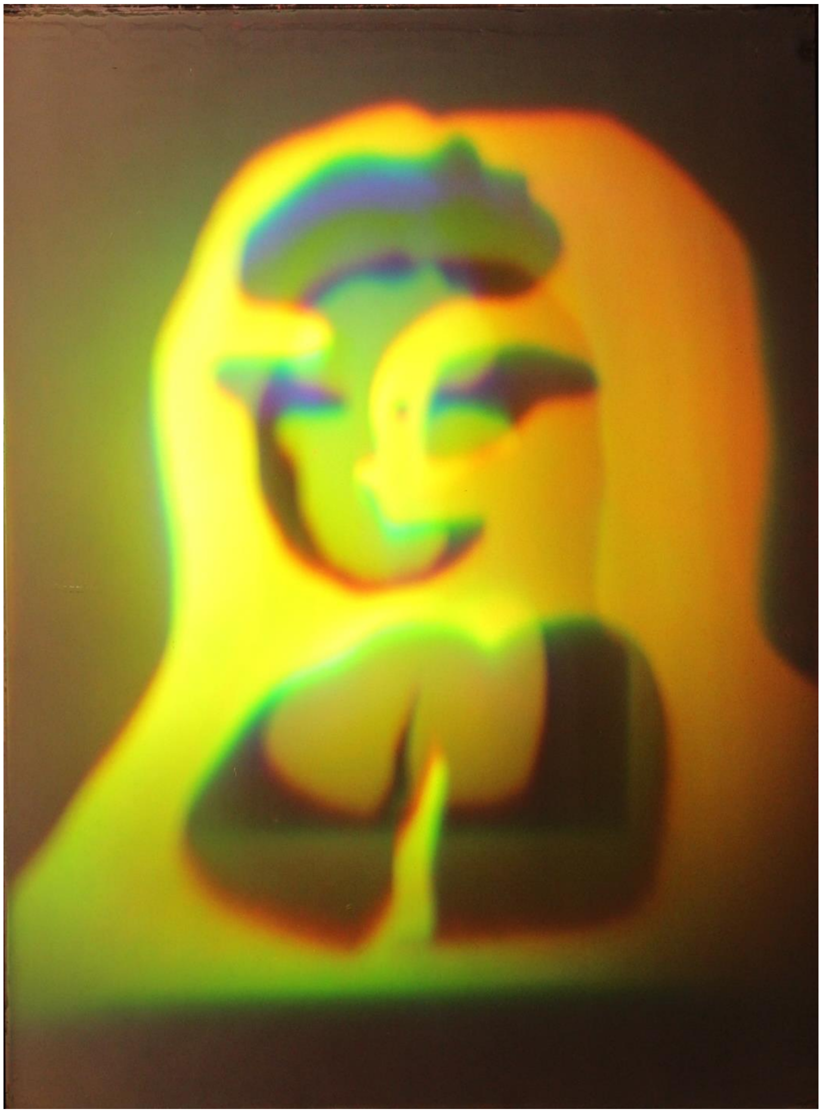

FIG. 2.3.6: ***Mona Lisa*** **(1982) by Kenneth Harris. Lake Forest College Hologram Collection.**

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.[18] 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 was 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. 2.3.7: *Xylophone Interferogram* (1988) by Pierre Boone. Lake Forest College Hologram Collection.

Eighth is this composition by Larry Lieberman, made in 1989 in Miami, Florida. It is a multicolor white light reflection hologram depicting an artistic representation of cells in the human body. Unfortunately, we do not know very much about this hologram, and I was unable to find any sources to provide additional information. Wesly 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.

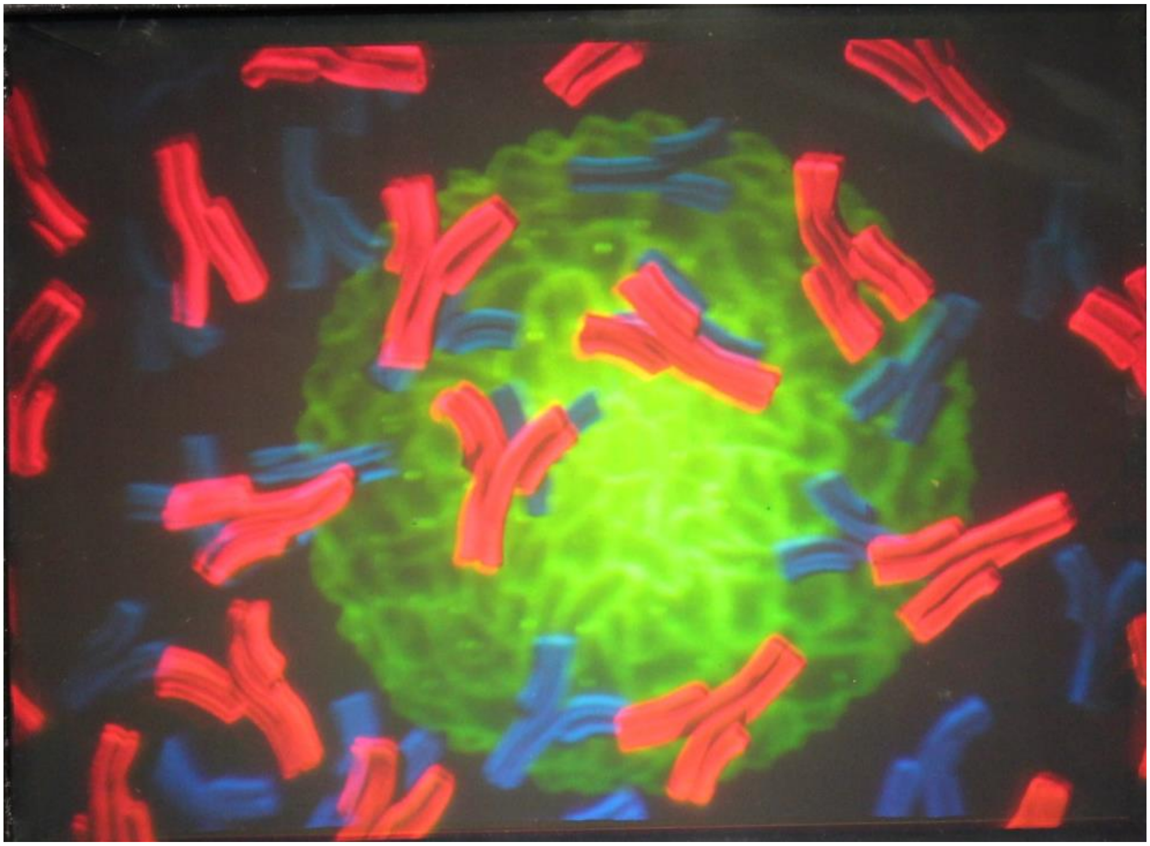

FIG. 2.3.8: ***Untitled*** **(1989) by Larry Lieberman. Lake Forest College Hologram Collection.**

Ninth, we have *Saturn*, made by Lon Moore in San Francisco, California 1978. *Saturn* is a small white light reflection copy from a laser transmission master hologram. This particular composition is very deep (despite its small size—at 3.5 by 5 inches, it is 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. (According to Wesly, the planet is made of a jawbreaker from a bubble gum machine, and the shimmering backdrop is crumpled aluminum foil!) Again, like the previous hologram depicting the T cells, this hologram combines the topics of art and science, consequently benefiting each.

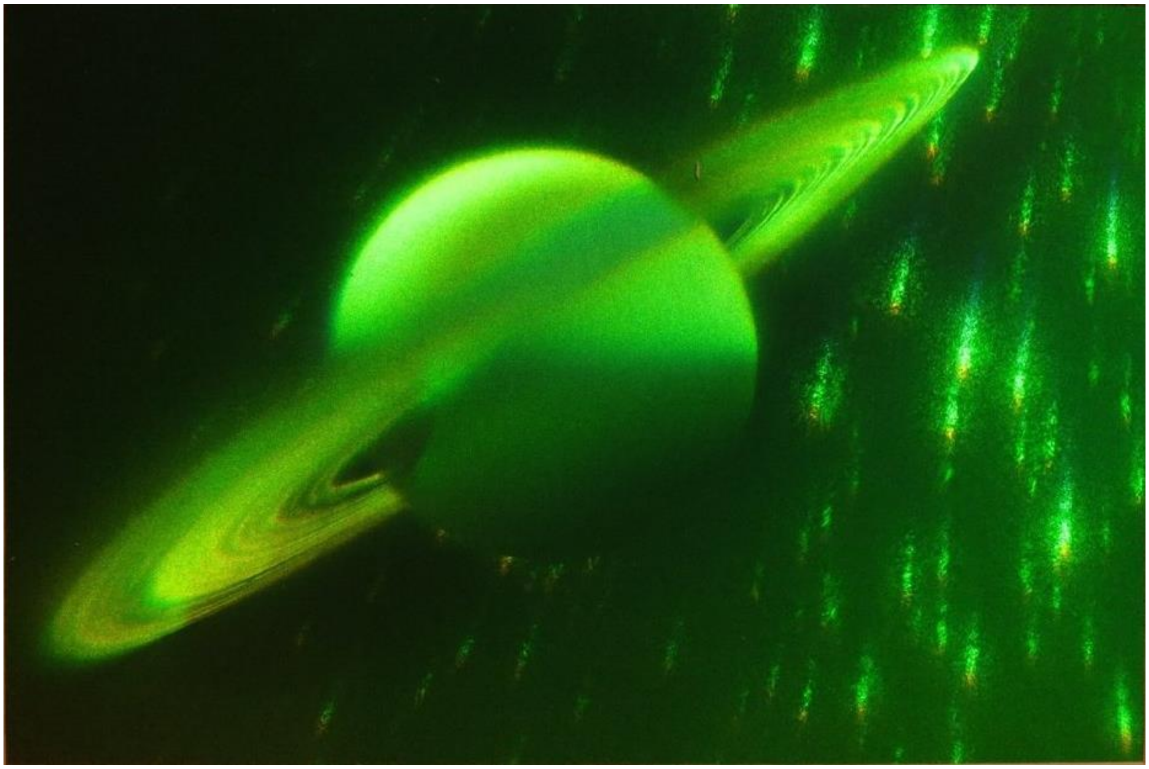

FIG. 2.3.9: *Saturn* (1978) by Lon Moore. Lake Forest College Hologram Collection.[21]

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.[22] I am assuming the artist and year based on similarities to another hologram pictured in the 1985 International Exhibition of Holography's Catalogue of Holograms.[22] 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, Wesly recognized the doll as Alice immediately upon viewing the hologram.

We encountered many "dead" holograms during the time that we were viewing all of the holograms in Lake Forest College's collection. That is, their emulsion deteriorated during the decades since their births. We believe that we may have come across other holograms from this series in the college's collection, but that they did not survive the decades of storage.

FIG. 2.3.10.a: ***Alice in Wonderland II*** **(1984) by Jonathan Collins and Pascal Gauchet. Lake Forest College Hologram Collection.**

FIG. 2.3.10.b: ***Alice in Wonderland I*** **(1984) by Jonathan Collins and Pascal Gauchet.[22]**
Jonathan Ross Hologram Collection[17] (not displayed in the gallery).

The eleventh hologram in the gallery is Nancy Gorglione and Greg Cherry's *A Cup of Gold Fish* from 1992.[23] 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.

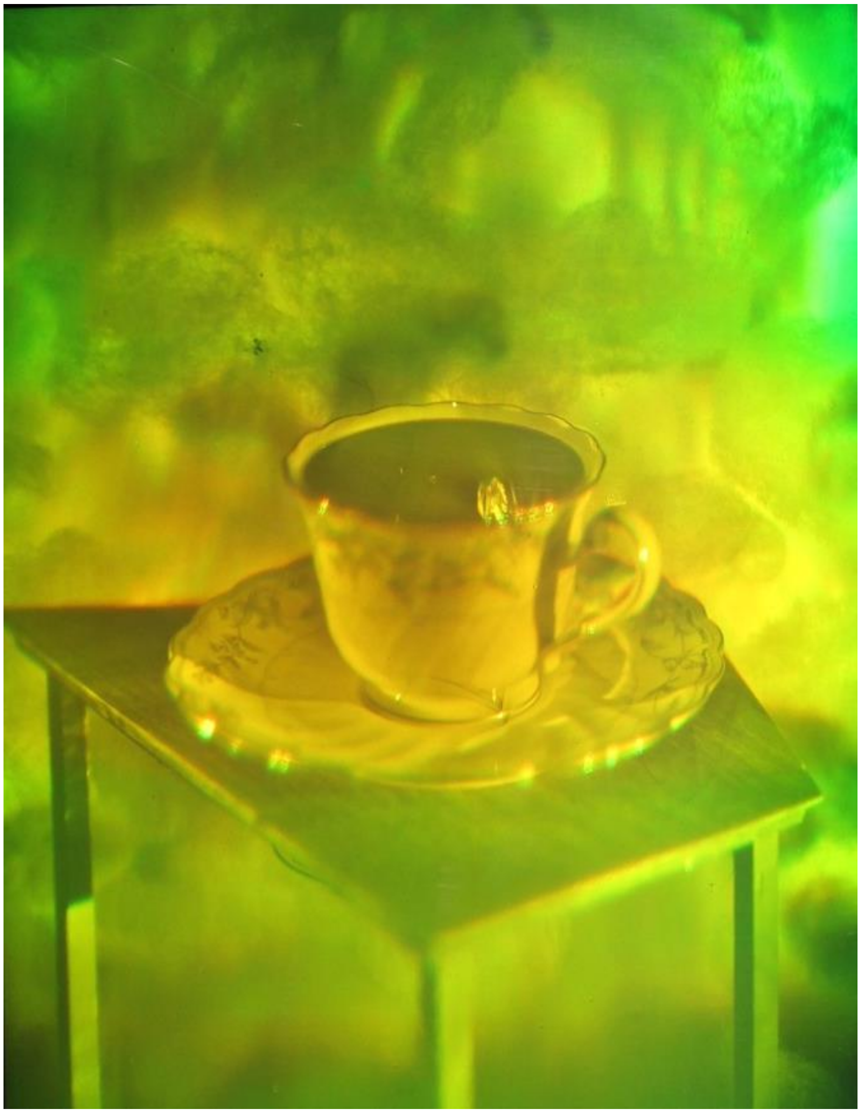

FIG. 2.3.11: *A Cup of Gold Fish* (1992) by Nancy Gorglione and Greg Cherry. Lake Forest College Hologram Collection.

Twelfth, we see American artists Joseph Burns' and Serge Honinow's *Nested Arrays*, from 1981.[20] 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 hypercube. 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).

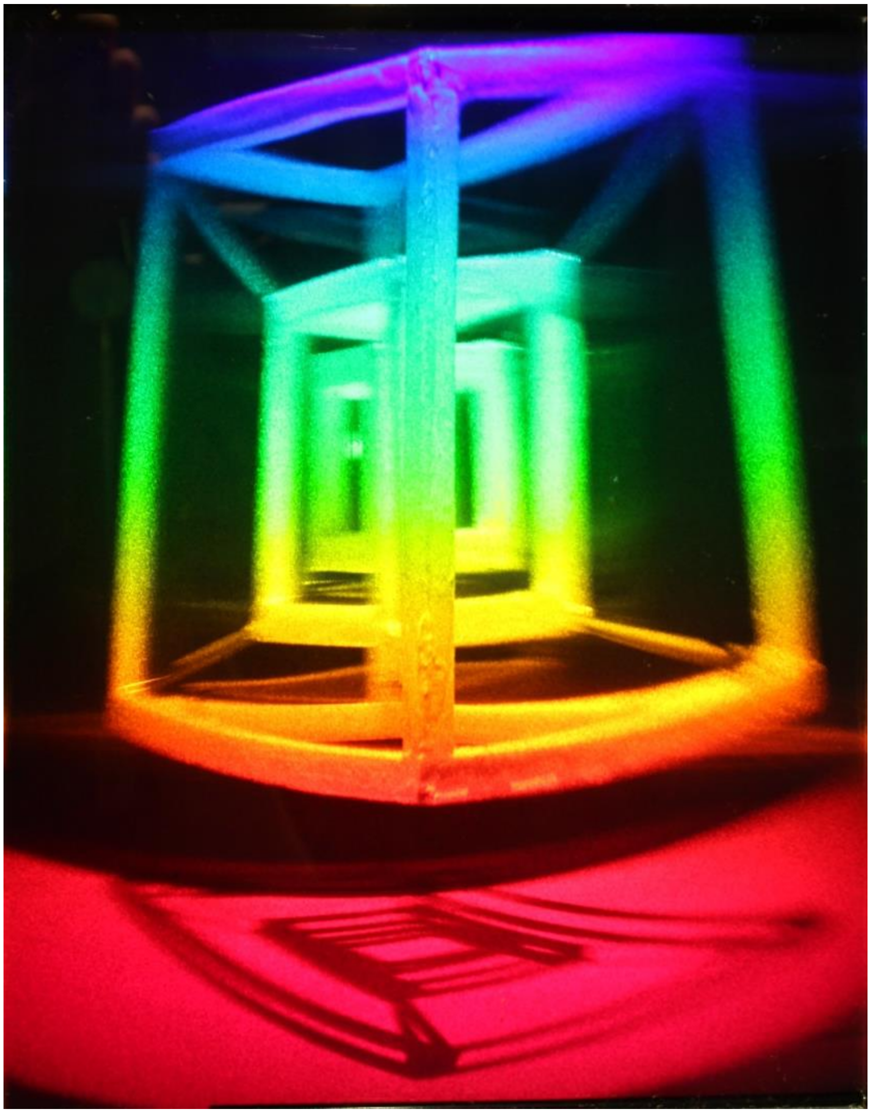

FIG. 2.3.12: *Nested Arrays* (1981) by Joseph Burns and Serge Honinow. Lake Forest College Hologram Collection.

Thirteenth in the gallery is an untitled computer-generated white light reflection hologram made by Nick Phillips in 1988.[24] 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.[24]

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."[24]

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.

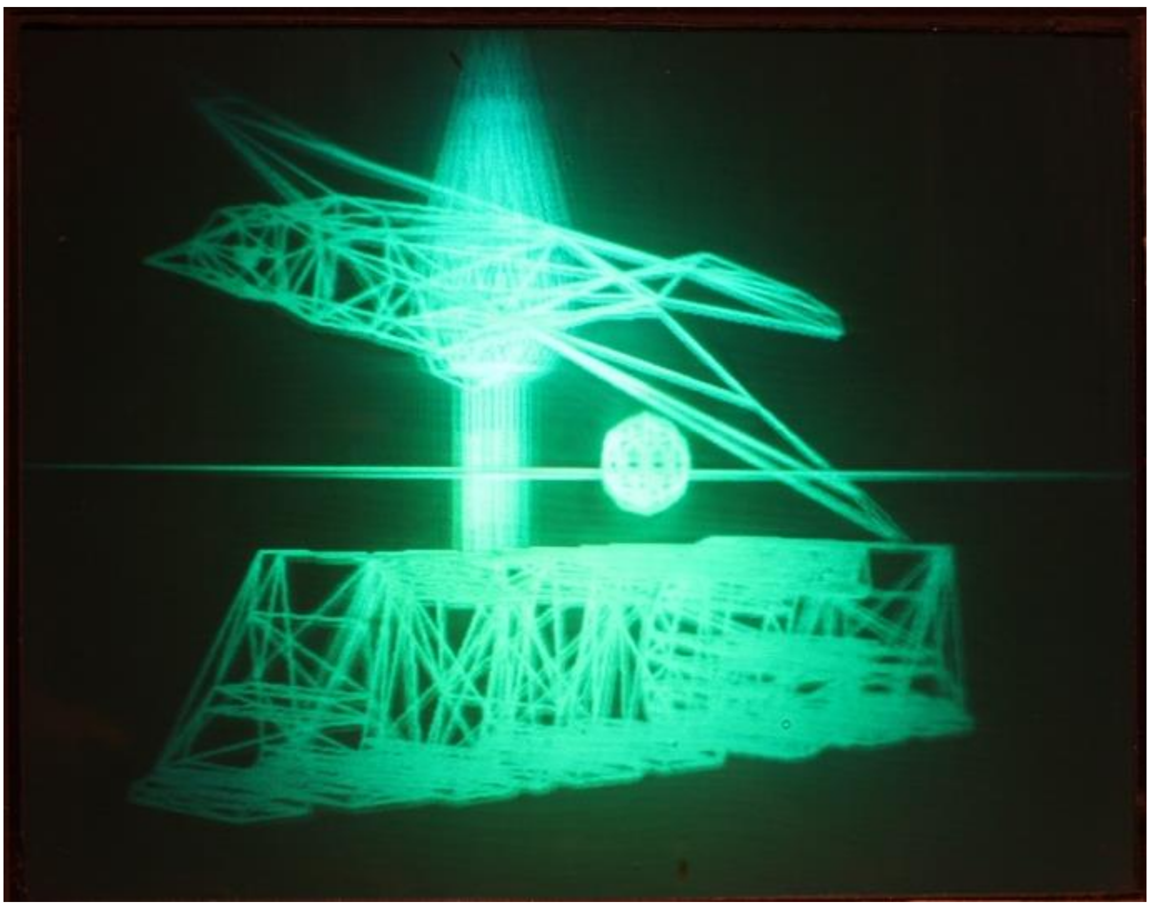

FIG. 2.3.13: *Untitled* (1988) by Nick Phillips. Lake Forest College Hologram Collection.

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, a flea is presented, magnified hundreds of times to a fairly off-putting size, much larger than life. It was visualized using a scanning electron microscope. In this way, it acts as a sort of reminder of Gabor's work to improve the election microscope in the 1940's, which led to the invention of holography. While this image and the previous image were holographically recorded 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. 2.3.14: *Flea* (1988) by Nick Phillips. Lake Forest College Hologram Collection.

Fifteenth is Larry Lieberman's *Abstract*, from Miami, Florida in 1989. It is 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.

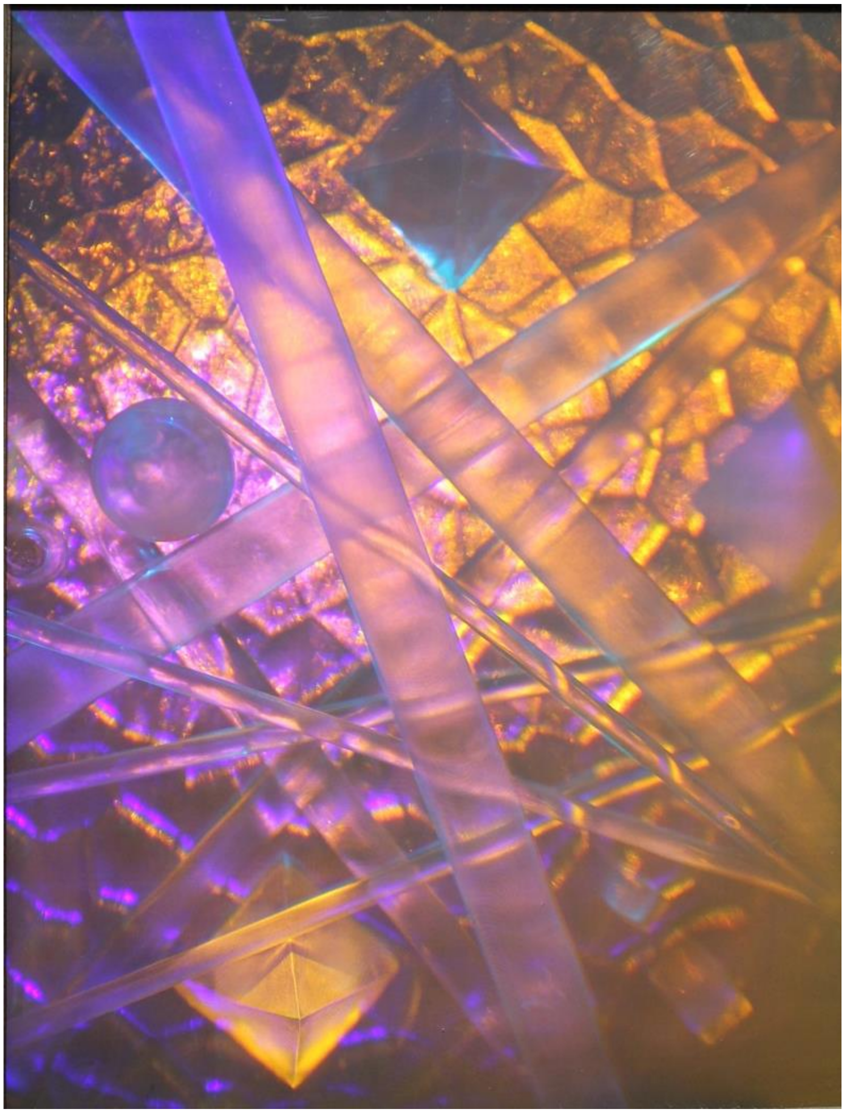

FIG. 2.3.15: *Abstract* (1989) by Larry Leiberman. Lake Forest College Hologram Collection.

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 is 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 is not 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 is an extremely successful hologram which presents an incredibly convincing image of the holographic object.

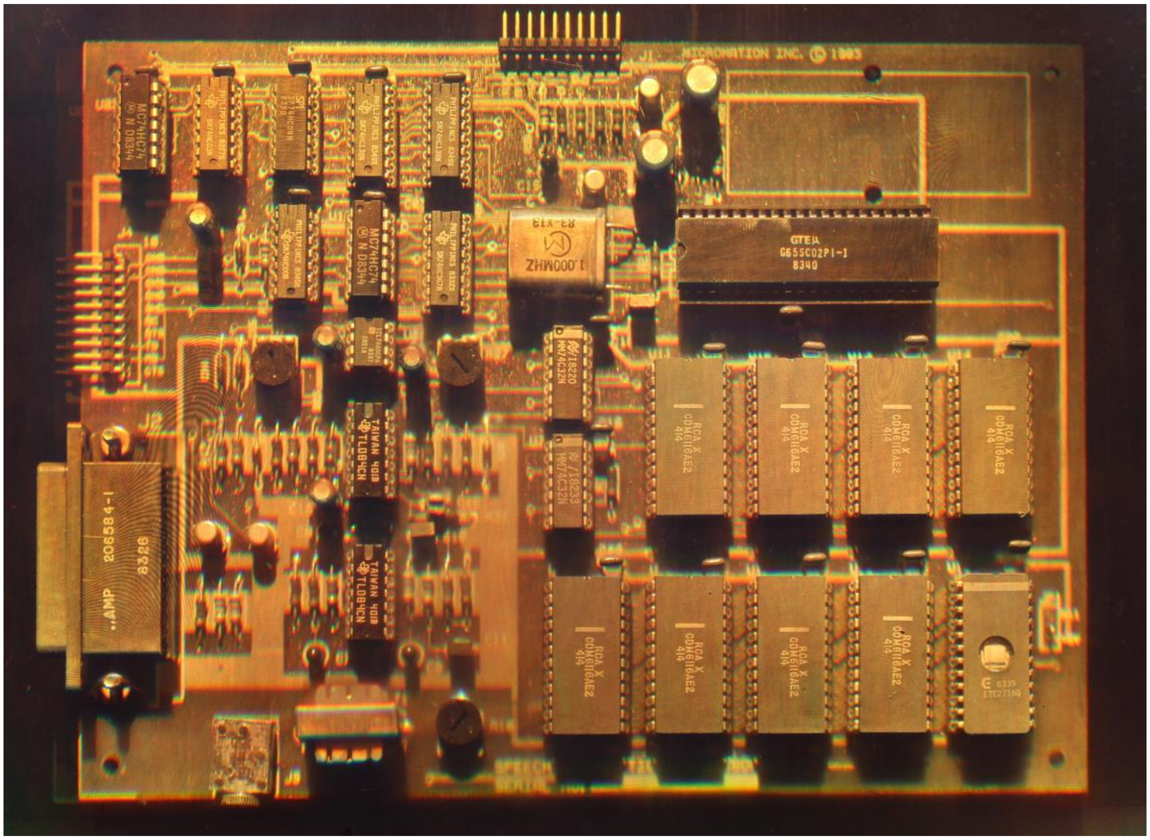

FIG. 2.3.16: *Circuit Board* (1991) by Richard Rallison. Lake Forest College Hologram Collection.

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).[18] 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 did not have any information about this hologram, until we were visited by Bjelkhagen himself, who was able to provide helpful context.

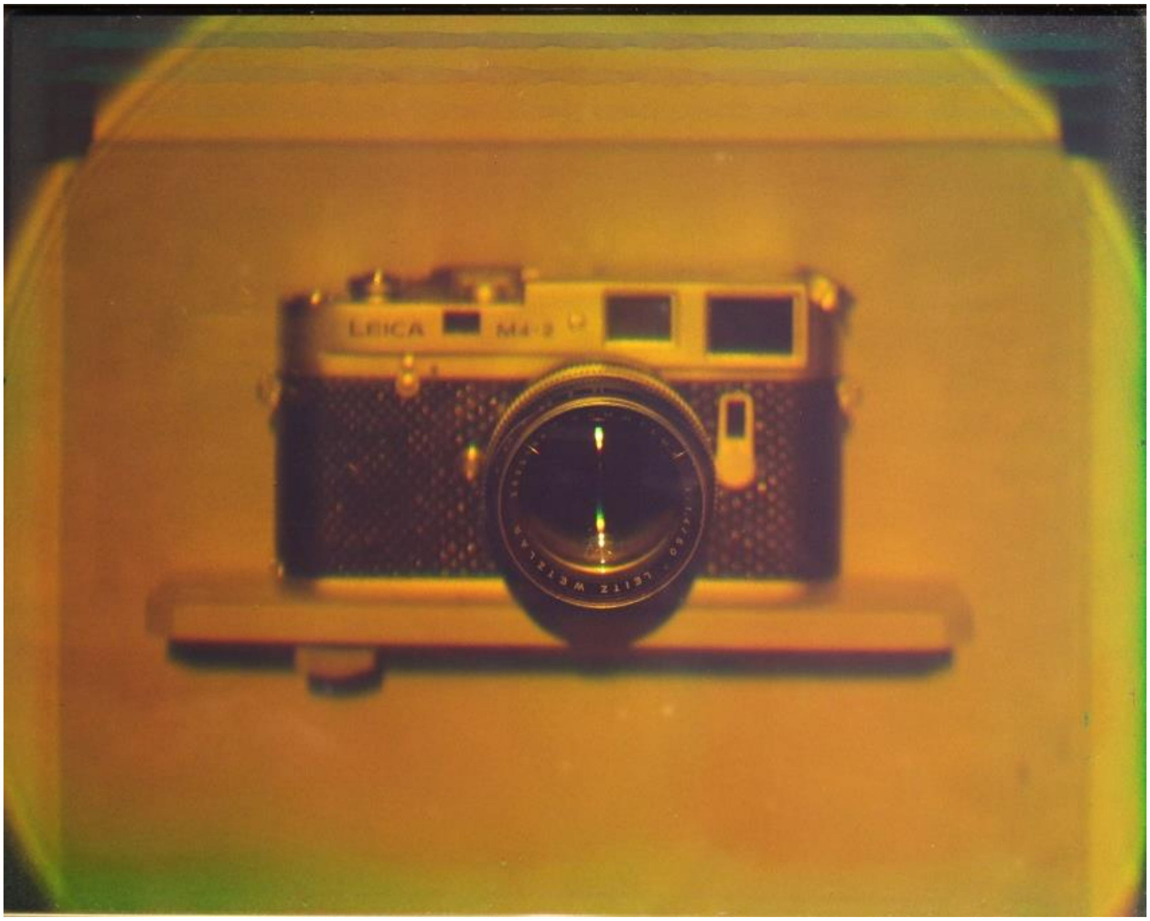

FIG. 2.3.17: *Golden Leica* (1981) by Hans Bjelkhagen. Lake Forest College Hologram Collection.

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"). It was included in Jeong's *International Symposium on Display Holography: Proceedings, 15-19 July 1991, Lake Forest Illinois*.

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."[25] 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.[25] This is why it was possible to make a hologram like this, of a large, outdoor space full of incoherent light.

FIG. 2.3.18: ***1991 International Symposium On Display Holography Participants*** **(1991) by Steven Smith. Lake Forest College Hologram Collection.**

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.[26] 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 shallow 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 (measured from an axis perpendicular to the surface of the hologram). The shallowness of this angle has always made the image of the lion difficult for us to view in the past, because it is 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.

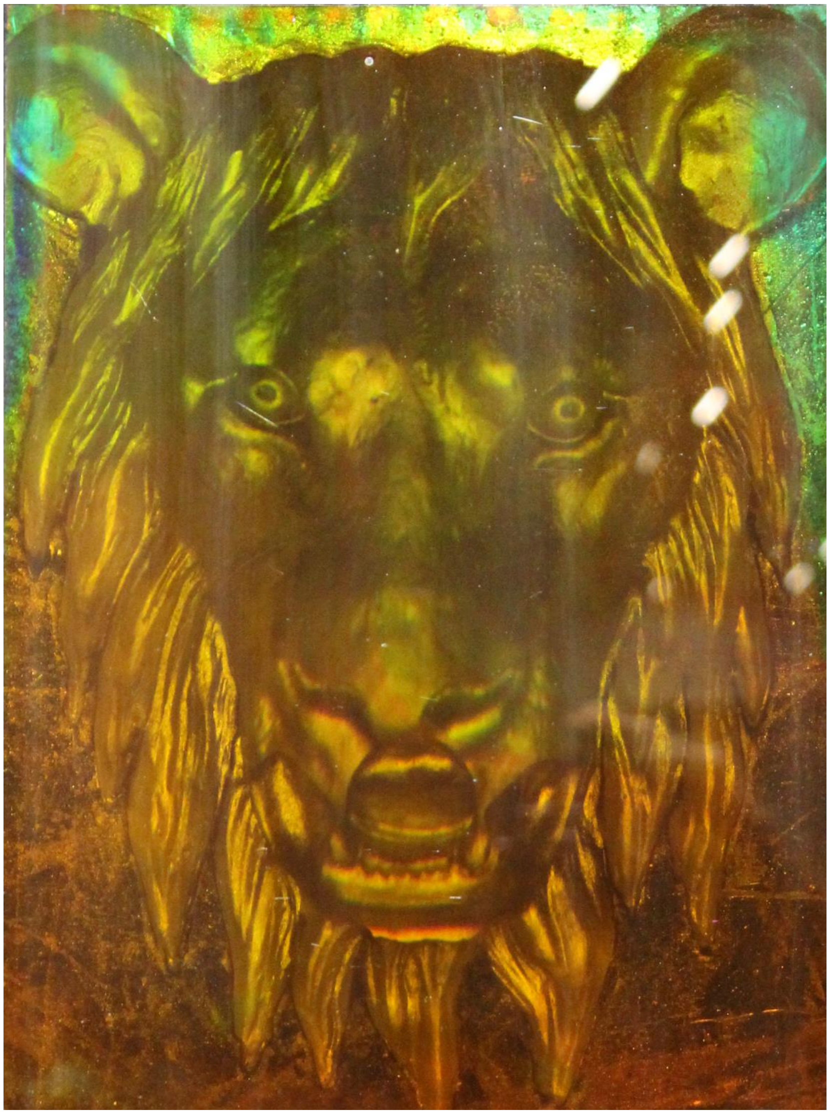

FIG. 2.3.19: *Lion* (1976) by NIKFI. Lake Forest College Hologram Collection.

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 appear to be stickers. These are excellent quality holograms which show a wide variety of the colors that can be recorded using true-color methods of holography. Making true color holograms requires the use of three different colored lasers to expose the film or photographic plate.

Unfortunately, we know relatively little about these true-color sticker holograms. Something like this is more likely to have been produced by a company rather than made by an ordinary holographic artist. Wesly believes that it may have been manufactured in the early 1990's by Dai Nippon, a Japanese printing company.

FIG. 2.3.20: *Untitled (Stickers)* (early 1990's) by Dai Nippon. Lake Forest College Hologram Collection.

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 College, and a number of other compelling holograms of objects or composed sculptural scenes. Unfortunately, I have been unable to identify the artists who made many of these transmission holograms, but I know that many of them were once students at Lake Forest College.

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 collimating 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 of a horse in a viewing apparatus inside one of the cabinets in the gallery. Many cylindrical holograms are displayed on spinning mounts, to allow viewers to see the hologram from all angles, but this particular viewing mount is stationary. We placed three mirrors at right angles around the sides and back of this apparatus so that all sides of the hologram can still be viewed (and to get an interesting “infinity mirror” effect, turning the singular image of a horse into more of a merry-go-round).

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 would 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 aimed 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.

Figure 1: FIG. 2.3.21: Photograph of the Lake Forest College holography gallery in May 2019

IV. EXPERIMENTATION AND PRODUCTION

A. Apparatus

Essentially, when making a successful hologram, a laser beam has 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 are 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 does not 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 will 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).

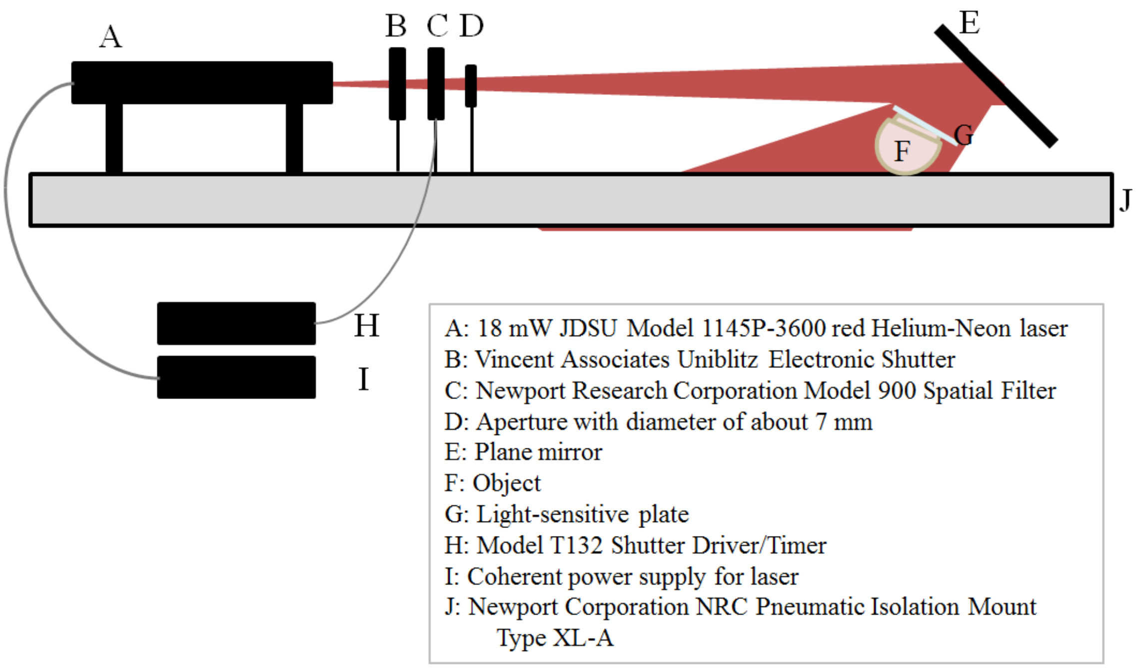

FIG 3.2.1: Apparatus used for making white light reflection holograms

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 should not 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 is 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 have not had great success yet. We have 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.

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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