2013-10-04

Light: The Fundamental Expression

Dunkley, Kirk

UNIVERSITY OF CALGARY

"Light: The Fundamental Expression"

by

Kirk Dunkley

A PAPER

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF FINE ARTS

DEPARTMENT OF ART

CALGARY ALBERTA

SEPTEMBER, 2013

ABSTRACT

This paper is in support of two years of artistic research concerning ideas about light as the ultimate medium for sculptural expression. Specifically, this paper makes a case for light as the ultimate expression of movement, space, time, and the notion of infinity.

Curiosity is a human condition. We make observations about our environment, embark on scientific and artistic explorations, and attempt to formulate and answer questions. Of the senses that we have, vision is the most pronounced, and is prominent in the way that we make these observations. The paper takes this a step further to show how light is fundamental to the human visual experience, and is the foundation for information that we gather about our environment.

The writings go on to discuss man's fascination with light and movement in the environment, and how artists and scientists have explored light as a material, a medium, a signifier of time, and an indicator of space. The paper examines how parallel discoveries in science and fine art have informed the advancement of technologies used to explore and articulate light, leading to increasingly minimalist examples of kinetic light-based artistic expressions. Examples are presented showing the evolution of kinetic art and its convergence with light-based explorations. In tandem with technological advances, this convergence and evolution has resulted in an ultimate expression of space, time, and movement to date, the LASER.

The paper concludes by discussing the evolution of my own work throughout the course of the program. I outline my transformation as an artist, moving from the creation of tangible artifacts to the creation of light-based installations, and my own explorations with various types of light technologies to articulate movement, space, time and the notion of infinity.

ACKNOWLEDGEMENTS

Ron Kostyniuk, my mentor and supervisor, whom I have known since my first year as an undergraduate student in 2003. Thank you for your unwavering guidance and support throughout the graduate program, and in the years leading up. I recall one of our first conversations, where you said “art sustains me”. These three words have stuck with me after all these years, and have become my own personal mantra as I navigate my way through a life of discovery and creation. Thank you for helping me to realize and develop my true passion.

Clyde McConnell, thank you for chairing my graduate committee and assisting me throughout the program. Your numerous art historical suggestions helped me to establish connections between light, sculpture and installation. Also, thank you for the extremely effective critiques of my writing.

Peter Deacon, whom I have also known since 2003, thank you for your absolute support over the years and for chairing my graduate program. Your unique perspective allowed me to “see” things in completely new ways, and has been instrumental in the development of my conceptual research interests.

Eric Cameron, whom I have also known since my first year as an undergraduate student, thank you for your years of guidance and support. Thank you for allowing me to assist you with your drawing classes, and for the many enlightening conversations throughout the graduate program.

To my parents. Mom and dad, thank you for always standing behind me, and pushing me to press on. My journey through academia has been a long one, and I thank you for your patience and support. I am forever indebted to you for your guidance, for believing in me unconditionally, and encouraging me to make the absolute most of myself.

To my beautiful wife, Kayla. Thank you for your absolute faith in me. To all the late nights setting up installations, contributing your voice to my work, listening to my ideas, and supporting all of my projects. I couldn’t be more blessed than to have you by my side. You are always first in my heart, and I extend the most grateful and loving devotion to you.

For my glowing light.
My angel, my wife,
Kayla April Dunkley

TABLE OF CONTENTS

LIST OF FIGURES AND ILLUSTRATIONS

EPIGRAPHS

a. Isaac Asimov, *The Roving Mind*
”How often people speak of art and science as though they were two entirely different things, with no interconnection…that is all wrong. True artists are quite rational as well as imaginative and know what they are doing; if they do not, their art suffers. True scientists are quite imaginative as well as rational, and sometimes leap to solutions where reason can follow only slowly; if they do not, their science suffers.”

b. James Turrell
“Light is not so much something that reveals, as it is itself the revelation.”

c. Paul Cezanne
“[Art] first of all is optical. That’s where the material of our art is: in what our eyes think.”

FOREWORD

At the core of our being, we are compelled to explore and understand our environment. We are universally drawn toward the phenomena in our world that mystify our imaginations and drive our inquisitions. Through experimentation and creation, we attempt to build models of our world using both rational and creative modes of thought.

Figure 1 Handful of treasure (Sudarshan, 2008)

Oftentimes these processes begin before we are even able to walk or verbally articulate our thoughts. A child begins experiencing the world almost all at once; hearing, seeing, tasting, smelling new things, experimenting with the tactility of the surroundings, constantly bombarded with new perceptual puzzles to solve. This process is ongoing and exponential. As we develop and mature, our mental faculties become capable of processing more elaborate questions about our environment. Just as it is in human nature to be curious about our external environment, we often project our curiosity inward, and question how our minds interpret and process the external world.

There is a tendency in popular psychology (and popular culture) to generalize the function of the brain into left and right parts- that is, the left performing all creative thinking, the right is responsible for rational thought. Creative endeavours involve making new ideas while thinking intuitively, while rational occupations involve reducing the unknown to fragments of simplified data so as to categorize and understand various relationships at play. One mode of thought attempts to build subjective models of phenomena, while the other attempts to deconstruct phenomena using pure objectivity. Such a divide arises in discourse surrounding fine art and science, generally the two are considered to be quite polar. “The relationship between art and science, being taken for granted, was preyed upon from the outside until a complete divorce was accomplished” (Halvey, n.d.). The artist is known as an erratic being, reacting to the environment in spontaneous outbursts of emotion, flinging paint haphazardly onto canvasses. The scientist, on the other hand, is seen as cool, calculated and methodical, reacting to the environment in an objective and meticulous manner with no margins for human error or spontaneity.

Contrary to what popular psychology might suggest, the artist must often proceed in a rational manner in order to understand their own conceptual drive to develop sustainable creative methodologies. The scientist similarly, may allow his or her mind to operate beyond the confines of method so as to remain open to new interpretations of data. As recently as the 19th century, it was common knowledge that our best thinkers in science were also artists, and that artists were also largely interested in the scientific discoveries of their time. It was not even considered necessary to mention the artist-scientist as a novelty, as it was a given that both realms were needed for a human being to have a balanced ability to rationalize and create.

A prime example of the interpenetration of rational and intuitive modes of thought is Albert Einstein. Einstein believed insight did not come from logic or mathematics, but that insight comes, as it does for artists, from inspiration and intuition (Einstein, & Calaprice, 2005, 22, 287, 10). Einstein believed that "All great achievements of science must start from intuitive knowledge ...intuition and inspiration...." and regarded imagination to be more important than knowledge. He believed that this was why at times he felt certain about his ideas while not knowing the why (Einstein, & Calaprice, 2005).

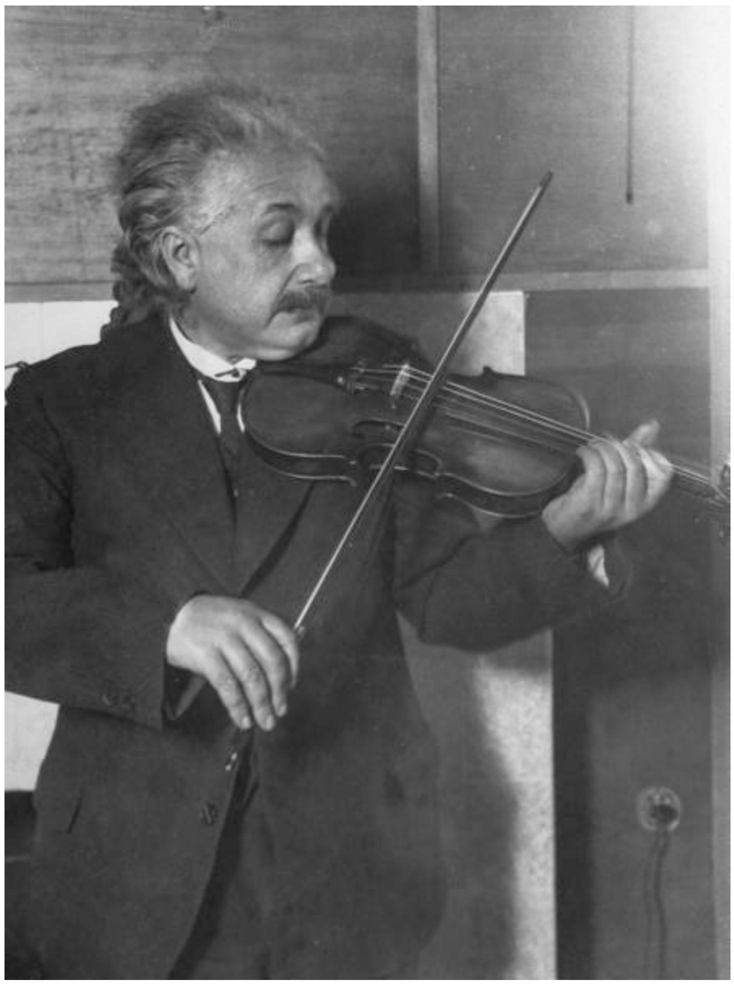

Figure 2 Einstein Playing Violin (Hope, 1921)

Einstein was a keen and talented musician, and was known not only for his scientific discoveries, but also his ability to play violin and piano. He believed that his discoveries were the result of musical perception. For Einstein, music was not just a hobby, but the driving force behind this intuition. His thoughts were directed by music in new and creative directions. . Einstein attributes his greatest discovery, the theory of relativity, to musical perception. (Suzuki, 1969, 90). “He never thought in logical symbols or mathematical equations, but in images, feelings, and even musical architectures” (Wertheimer, 1959, 213-228); According to Arthur J. Miller, “he preferred the highly structured, deterministic music of Mozart, and imagined Mozart plucking melodies out of the air as if they were ever present in the universe. Einstein thought of himself as working like Mozart, not merely spinning scientific theories but responding to nature, in tune with the cosmos” (186). "Whenever he felt that he had come to the end of the road or into a difficult situation in his work, he would take refuge in music, and that would usually resolve all his difficulties" (Clark, 1971, 106). According to Einstein’s sister Maja, after playing piano he would get up saying, there, now I've got it (Sayen, 1985, 26). This difference in thinking is what enabled Einstein to make breakthroughs in science by seeing the world through the eyes of a creator.

Our creative insights can be verified by scientific method, while creativity fuels science. The scientific method is how we “do” science, and although the scientific method requires findings to be empirically objectified, it is the artistic method that leads to new insights and is the very essence of this “doing”. According to astronaut, doctor, art collector, and dancer Dr. Mae Jemison, “science or art is a ridiculous choice”; our mission, says Dr. Jemison, is to “reconcile and reintegrate science and the arts”. Both the arts and the sciences are not merely connected but manifestations of the same thing, “the arts and sciences are avatars of human creativity — [they] are our attempt as humans to build an understanding of the world around us, and our attempt to influence things (things in the universe internal to ourselves and the universe external to ourselves)” (TED: Ideas Worth Spreading, 2009).

Chapter One: Panta Rhei

The Greek philosopher Heraclitus is attributed with the famous maxim "Panta Rhei" (everything flows) (New World Encyclopaedia, n.d.). Even before the epoch of pre-Socratic philosophy, there is evidence that man was aware of and very interested in depicting motion. Dragging the point of a stick through a surface of wet clay, a hard rock to etch a line into a limestone cave wall, or a finger tip or hand covered in pigment of ground rock or blood, Palaeolithic cultures were able to make their mark recording and expressing the moving world around them.

Many examples of these works—dating back as far as 30,000 BCE, according to radiocarbon analysis—are located in Spain and France. Cosquer Cave, near Marseille, France, contains numerous depictions of marine life, including seals and fish (Adams, 2002, 32). Renditions of mammoths and horses, located in the Chauvet cave, in the Ardeche Valley, France, are also of significance (Adams, 2002, 34). The Hall of the Running Bulls, located in the Lascaux cave system in Dordogne, France, is perhaps the most famous example of Palaeolithic art. Depicted are a herd of running bulls rendered in coloured earth pigments, portraying motion using a number of basic drawing and painting techniques. These include overlapping shapes, and bold linear outlines to suggest that movement is occurring, and unstable body positions implying movement is to follow (Adams, 2002, 37).

Figure 3 Running Bulls in Lascaux (Perez, 2007)

Throughout the ages, man has also demonstrated an acute awareness and appreciation for light. Ancient Greek culture celebrated the solstices as well as the equinoxes, using them as index points to mark the passage of seasons. Ancient Mesoamerican civilizations developed a calendar based on the 365-day solar macro-cycle and the day and night micro-cycles, using it to plan many of their agrarian activities (Coe, & Koontz, 2002, 11).

Figure 4 Mesoamerican Calendar (Comondante, 2009)

Numerous ancient architectural forms exist that stand as testaments to man's interest in light, particularly the motion of celestial bodies in the day and night sky. It is believed that Stonehenge may have been an elaborate form of sundial used to predict seasonal changes and astronomical phenomena. Scholars also believe that Stonehenge, as well as the other cromlechs throughout Western Europe, were sites of celebration for solstices, equinoxes, and seasonal changes brought about by the cyclical change of the sun's angle of incidence to the sky (Adams, 2002, 47-49).

The great pyramids of Giza, Egypt, are among the largest structures ever made and are the only surviving "wonder" of the ancient world. An engineer from Belgium, Robert Bauval, observed that the strange arrangement of the pyramids was almost identical to the three stars in Orion's Belt constellation. Egyptian culture believed that Orion's Belt was home of the god Osiris and that the constellation bore a resemblance to him. Thus, they used the light of the stars to align the placement of the pyramids. Bauval also calculated that in 2500 BCE, the airshafts located on the north walls of the pyramids would have pointed directly at Orion's belt, while the South facing vent would have pointed directly at the star Sirius, which the Egyptians believed to be sacred to Osiris's consort, Isis. The Egyptians believed that the pyramids were not only monuments to the pharaohs, but perhaps gateways through which the souls of the dead pharaohs could travel to the light of the stars, as well as between Orion's Belt and Sirius (Bauval, n.d.).

Each of these examples depict man's interest in light and movement at the very early stages of human history, but more importantly, we make observations about these forms in the same way that their makers made observations about the world around them. After more than 30,000 years of human existence, our perception of the world around us "...first of all is optical. That's where the material of our art is: in what our eyes think." (Paul Cezanne) Our initial impressions of these forms, be they sculpture, painting or architecture, are made through the eyes. The sense of sight is the most developed and pronounced of our senses, and is the foundation for a large part of our sensory experience of the environment around us. Chapter two will examine the figurative and literal importance of visual perception, and will explain just how central vision is to the human perceptual experience.

Chapter 2: Vision

The process of visual perception is so basic and profound an experience in human existence, that we are compelled to articulate important mental activities in terms of vision. To see is to understand, to have a viewpoint is to take a conceptual position. To look into something is to investigate. (Sarcone & Waeber, 2011, 21).

Reference to vision is made constantly in everyday language. Of the more literal idioms that relate almost directly to the sense of vision, the phrase “beauty is in the eye of the beholder” is a metaphor drawn from the subjective visual perceptual experience. On the contrary, “seeing eye to eye” implies that individuals can share the same perspective and have a common understanding of something. An individual with unusual powers of foresight is often regarded as a person of vision, or a visionary. Even in defining the notion of a visionary, it is almost impossible to escape the notion of vision; the word foresight makes direct reference to “seeing” or experiencing premonitions about the future.

The experience of vision is so engrained in our language that we explain emotional behaviour using it as a metaphor. “Blind rage” describes absolute anger, whereby actions arising from emotional over-response are taken without regard for consequences. Extreme cases are recognized and diagnosed by behavioural specialists as Berserker-blind rage syndrome. On the contrary, the widely known cliche’ “Love is blind” implies that love can impair vision. Light and dark, both precursors to vision, are commonly used to describe contrasting relationships. “Brightness” can imply “intellectually gifted”, while “Dim” is a term often used to describe sub-par intellectual capacity. The phrase “a dark place” is often used to describe a period of depression, while “light at the end of the tunnel” is an idiom for perseverance and hope.

We use many words in our daily vocabulary that imply vision. We use the word "eye" figuratively to denote central positions in space, for example, bulls eye, eye of the storm. In Western religion, the notion of vision is used to denote the central position of our divine creator, god. God is regarded as omniscient, which by definition means "all-seeing, and all knowing".

The term "omniscient" is not isolated to Western religions, but is recognized universally throughout all religions of the world. In the Hindu religion, omniscience is recognized as the third eye of clairvoyance; a gateway leading to realms and spaces of higher consciousness whereby perception is heightened, and an ultimate level of enlightenment is achieved.

Even the word "enlightenment" is derived from the word "enlighten", which is a synonym for both education (the acquisition of knowledge through learning experiences) and light. Given the definition of "enlighten" and "omniscient", it is not a stretch to understand light as a direct metaphor for knowledge, and vice versa. Omniscience is also related to the notion of "outrospection" or empathetic thought; that is not just looking outwardly, but directly experiencing the world through the perspective of others. The philosopher, Plato asked "…why should we not calmly and patiently review our own thoughts, and thoroughly examine and see what these appearances in us really are?" (Plato, & McDowell, 1973, 153). Plato was of course referring to the egocentric perspective of introspection, a term best known for its role in epistemology. Introspection is defined as "the act or process of shifting one's perspective inward, looking into oneself" in order to understand ones own conscious thoughts and feelings.

Through perspective and looking, the term "introspective" is dually rooted in the notion of vision. Many great thinkers of our time have engaged in dialogue surrounding existentialism from both introspective and outrospective points of view. Psychiatrist Carl Jung quite beautifully and profoundly describes this dual perspective relationship as follows: " [He] Who looks outside dreams; [and he] who looks inside, awakens." Either way, Jung believed that "…the sole purpose of human existence is to kindle a light in the darkness of mere being" (Jung, 1963).

Vision and Light

In absolute terms, vision is defined as having the sense of "sight", that is the ability to perceive objects with the use of the eyes. Science has afforded us with an immense understanding of the sensory and cognitive processes involved in visual perception, but prior to the understanding that we now have, there was an intuitive understanding that vision and light are directly associated with one another.

In the fifth century BCE, Greek pre-socratic philosopher Empedocles postulated the cosmogenic theory of the four Classical elements. He wrote that everything in the world

Figure 5 The Four Elements (Liebermann, 2013)

was composed of the four “ ultimate roots” or elements; fire, air, earth and water. He believed that the human eye was no different than anything else, and had to have been made of these four elements as well. He postulated that the eye functioned in the same fashion as a lantern; light emanated from a burning fire within, and illuminated the darkness. In the case of the eye, Empedocles believed that the fire was the magical flame of Aphrodite, and thus would burn eternally and without causing injury. Sight was the consequence of this light reaching out and touching anything that happened to be in its path (Clegg, 2008, 20-24).

In fourth century BCE, Plato suggested that vision was analogous to the sense of touch; light originated within, and propagated out of the eye, touching objects and allowing them to be perceived (Clegg, 2008, 25).

This theory of vision, known as “extramission”, was the accepted scientific explanation for vision for approximately one thousand years, and was supported by common observations such as the brightly lit reflections from animal eyes in low light conditions. The custom of saluting in the military is believed by some to stem from the habit of Greek soldiers shielding their eyes with their hands from the bright light emanating from the eyes of their commanders.

Aristotle was among the first to reject the extramission theory of vision. Aristotle declared that it was unreasonable to hypothesize that seeing occurs by light leaving the eye; if this were the case, than one should be able to see in pure darkness. Other critics suggested that it was unlikely that a visual ray emitted from the eye could traverse vast distances instantaneously, for example, from the eye to the stars. Supporters responded, suggesting that light from the eye must move at infinite speeds; how else could one see the night’s stars immediately, between blinking and closing the eyes. In a revolutionary fashion, Aristotle proposed an opposite theory of vision called “intromission”. The theory of intromission speculated that light rays must originate from objects, and that these rays would enter the eye in order to impart vision. Although Aristotle proposed a logically sound model of visual perception backed up by common observations, it was not immediately accepted as the “new” model of vision, or even as an alternate model (Ayliffe, 2013).

Following a millenium of dispute over the emission and Aristotelian intromission theories of vision, the experiments of the Arabian physicist, Ibn al-Haytham (Alhazen) finally proved that Aristotle’s theory of vision was correct. In a seven volume manuscript entitled “*Book of Optics*” Alhazen outlined a variety of scientifically sound theories explaining the mechanics of numerous optical phenomena. In the *Book of Optics*, Alhazen verified the mechanics of reflection, refraction, lenses, mirrors, the various structures and inner workings of the eye, pinhole cameras, and a host of other optical subjects through a battery of experiments. Most importantly, Alhazen was the first recorded individual to scientifically prove that sight was the consequence of rays of light reflecting off objects, and entering the eye to form an image. Alhazen offered not conjecture, but theories backed by experimental verification, reducing the extramissionist theory of vision to a metaphor for the human gaze (Clegg, 2008, 32-35). Curiously, though we now hold intromissionist theory as fact, Winer et al. have found evidence that as many as 50% of American college students believe in extramissionist theory (Winer, Cottrell, Gregg, Fournier, & Bica, 2002, 417-424).

Visual Processing

Following the invention of the microscope in the 17th century, a vast number of discoveries were made in the field of biology. Scientists began to understand the presence and function of cellular structures in plant and animal tissue, and before long, new discoveries were made in the field of ophthalmology. As observational technologies advanced, scientists were able to look deeper, and perform more elaborate experiments. Scientists asked questions about the various sensory organs of the body, and how these components worked to create a cohesive perceptual experience.

The human brain consists of four main areas; the visual, auditory, somatosensory, and motor regions. In all mammals, including humans, the visual region is the largest and most highly developed of the four main subdivisions in the brain. The human

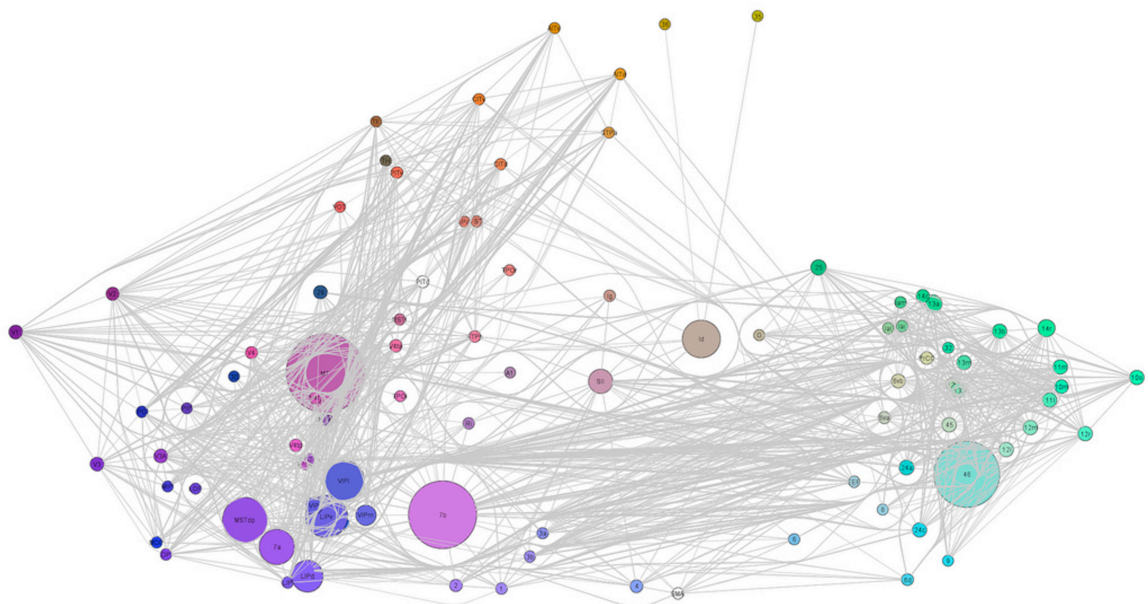

Figure 6 Neural Pathways (Sandberg, 2011)

visual system is complex, requiring numerous components of the eyes and brain to work together. It is responsible for our perception of light, colour, and movement, and is fundamental to our perception of space, and as we will see later, time. The complete visual system can be divided into regions responsible for the passive sensing and transmission of visual information, and the active perceptual regions responsible for creating interpretations of this gathered information.

In very general terms, the function of the eye is to convert light into information that the brain can process. When light reflects off of an object and enters the eye, it is focused through the cornea and lens onto the retina, an area of the eye densely covered with photoreceptor neurons (photoreceptors). Photoreceptor neurons can be divided into two distinct groups; cones and rods. Cones are located centrally on the retina, and are responsible for detecting colors and fine detail, while rods are dispersed throughout the retina, and allow us to sense motion and detect light in very dim conditions. As light enters the eye, it bombards the photoreceptors of the retina, resulting in a photochemical response producing tiny electrical currents. These electrical currents are gathered and transmitted to the brain via the optic nerve.

The perceptual process of vision begins when these electrical impulses reach a region of the brain called the visual cortex. Through an active process of selecting, organizing, and interpreting these impulses, the visual cortex is able to construct images of the environment comprised of numerous colours, textures, lines and shapes. These images are updated as we navigate through our environment, providing us with what we experience as a seamless mental representation of our surroundings. Via a mental comparative process involving these images, we are able to perceive and differentiate between our own movements, and movements occurring around us. We are able to make tactile inferences about our environment that protect us from injury. Our ability to recognize surface textures visually allows us to assess whether an icy surface or a coarse gravel bed are impassible. We are even compelled to react involuntarily to sudden movements that are perceived to be a danger, for example, blinking when an object passes too close to the face.

The visual cortex is so powerful in its ability to produce an image that it is able to create a perceptual experience even when details are obscured or out of view. For example, when we see an apple, we have a sense of its presence as a whole, and even though we are not able to see the apple in its entirety, we are able to experience it in its entirety. Surprisingly, the visual cortex only processes about one percent of the actual visual stimulus on the retina, and is able to create very accurate representations of this data by working in tandem with areas of the brain responsible for memory, interpretation, and attention. With such a tiny amount of the visual stimulus that we receive actually being perceived by the brain, it is amazing that we are able to create such accurate visual representations of our surroundings; however, every once in a while our visual perceptual system is fooled, and we experience a phenomenon known as an optical illusion. For centuries, scientists have been studying optical illusions, a phenomenon that results in dissociation between perception and reality. Although there is much debate in the scientific community about the perceptual processes involved in optical illusions, one hypothesis maintains that the visual cortex attempts to combine incomplete visual stimuli with a variety of conflicting images stored in memory in order to construct a complete image.

Figure 7 Optical Illusion (Hester, 2011)

Another hypothesis explains that they may be a result of the cerebral cortex perceiving the reality of the visual stimulus, and attempting to build a simplified visual model of that stimulus in spite of conflicting information stored in memory. Optical illusions are providing us with an ever-increasing understanding of the computational methods that the brain uses to construct visual experiences, and may one day allow neuroscientists to understand how to design neural prosthetics for patients with damage to the visual cortex region.

Vision is so central to the human perceptual experience that even those with limited or no visual sensitivity in part experience and process their environment visually at the cerebral level. In a study published in Neuropsychologia by Frederic Gougoux and Franco Lepore of the University of Montreal's Department of Psychology, when there is a deficit in the visual system that results in impaired vision or blindness, the human brain actually "rewires" itself so that the visual cortex becomes responsive to non-visual stimuli, and actively assists other parts of the brain in sensory activities; this re-wiring is known as neural plasticity. Other creatures are able to decipher their spatial surroundings and relative location with very limited, and in some cases, non-existent visual perception. In 1938, professor Donald Griffin discovered the existence of echolocation in bats. By broadcasting high-pitched audio frequencies, and listening to the echoes, bats are able to "see" in the dark. Zoologists have discovered a variety of other animals that rely on echolocation to perceive their spatial environment. While these animals have highly developed auditory cortex regions responsible for audio-spatial perception, studies indicate that humans are able to echolocate as well. However, echolocation in humans in part becomes a visual process. According to Dr. Lepore, brain activity measured using magnetic resonance imaging indicate that the blind use their visual cortex and are actually better at recognizing the origin of sound than those with sight. Studies indicate that the visual cortex assists the audio cortex in creating a spatial map based on audio perception. Furthermore, studies indicate that visual facial recognition is replaced by voice recognition in blind individuals, and not surprisingly, the visual cortex assists with this function as well.

Perhaps one of the more profound examples of visual perceptual neural plasticity is the case of a Turkish artist, Esref Armagan. Born completely blind, Armagan is able to create visually accurate perspective systems within his paintings, drawings, and sculpture. In 2008, Dr. Amir Amedi and Dr. Alvaro Pascual-Leone, scientists at Harvard University, undertook to learn more about neural plasticity, and analyzed Armagan's unique ability in detail. Using MRI imaging to analyze Armagan's brain function during his artistic activities, Dr. Amedi and Dr. Pascual-Leone made a startling discovery; Armagan's visual cortex appeared to be as active as anyone with normal visual function. What they later discovered was that Armagan's drawings were actually informed by tactile experiences that had been in part processed by the visual regions of his brain. Armagan's tactile sensitivity had actually developed in place of what would have been his visual sensitivity using regions of the brain responsible for visual processing (Amedi et al., 2008).

Related to neural plasticity is a neurological phenomenon called synesthesia. In humans, this is a well-documented condition. Synesthesia is a neurological condition in which stimulation of one sensory or cognitive pathway leads to automatic involuntary experiences in a second sensory or cognitive pathway. There are twenty-five documented variations of synesthesia ranging from the association of letters and numbers with colors to the association of words with tastes. There is a particular manifestation called sound to auditory-visual synesthesia, whereby individuals experience sounds visually as an array of shapes and colours.

Although these individuals are not actually being presented with any visual information, the visual regions of the brain are being stimulated by auditory senses, and are informing the individual visually about the environment. Synaesthesia extends the notion of neural-plasticity to individuals who have full sensory ability, and further indicate that the visual regions of the human brain are fundamental and central to the ways in which we perceive and understand our environment (Cytowic, 2002).

Returning to the basic definition, vision is defined as having the sense of "sight", that is the ability to perceive forms and movements with the use of the eyes. This perception of these things is dependent on the presence of light; light must interact with objects in order for them to exist in the visual realm. Light is the medium by which we experience visual perception. What is more, the perpetual movement of light allows us to sense the passage of time, and therefore light and movement are factors allowing us perceive time and progression. This sensitivity forces us to feel rhythms subconsciously and synchronizes us to our world. Our biological, mental, and physical rhythms come in circadian ebbs and flows, which are directly synchronized to the endless journey of the earth around the sun. The existence of light is critical to the visual experience, and the next chapter will explore the phenomenal presence of light, and its relation to movement, space, time and infinity.

Chapter Three: Light, A Phenomenal Medium

Light is among the absolute essential components of our universe, and is among the fundamental “materials” of life. “The most astounding fact, is the knowledge, that the atoms that comprise life on Earth, the atoms that make up the human body, are traceable to the crucibles that cooked light elements into heavy elements in their core, under extreme temperatures and pressures. These stars, the high mass ones among them, went unstable in their later years. They collapsed and then exploded scattering their enriched guts across the galaxy. Guts made of carbon, nitrogen, oxygen and all the fundamental ingredients of life itself” Dr. Neil deGrasse Tyson.

Light is the trace of all events in our universe. Because light moves at a finite speed through space, it allows us to look back in time to distant galaxies to further understand the absolute roots of our existence, the existence of all life, and the existence of existence itself. The further away an object emitting light is from us, the longer it takes for that emitted light to reach us, and thus the further back in time we are observing. For example, there is a 150,000,000 km void of space between our planet and our sun. At the speed of light, this journey takes eight and one half minutes, and thus, the light we see from the sun is from the past. What is more, it actually takes about 17,000 years for the photons generated in the core of the sun to reach the sun's surface before being emitted across space; the light that we observe from our sun was produced during the upper Palaeolithic epoch many millennia ago, and is finally reaching us now. This directly proportional relationship between distance and time is referred to as space-time. Despite the fact that we are seeing light from events taking place billions of years ago from distances that are unreachable, light is, in a sense, fresh; light is the conduit through which events of the absolute outer reaches of space and time are delivered to the immediate present. Light allows us to perceive events of the distant past as though they were occurring in real time. What is more, we can create it with chemical, nuclear, and mechanical means. However even as such, the source of all light, directly or indirectly is shared with the “crucibles” of all fundamental materials required for life. All light and all material are born of the stars, and are intimately tied to the universe and the beginnings of time. Light that we “produce”, regardless of the technology used to “create” it, is energy that was once created by stars and stored in various instances of chemical instability. Our technologies to “produce or create” light are in reality just methods of relieving these instabilities created many billions of years ago. When we produce light, we are in a sense, releasing light from the stars.

When considering the notion of infinity relative to spatial perception, one will typically consider the vast expanse of the universe. in 1928, Edwin Hubble demonstrated that the universe is expanding from a finite origin, a finite time ago. According to Stephen Hawking, the foremost expert on the origins of the universe, the universe is actually not infinite in volume, nor does it have an outer boundary because it appears to be forever moving away from an origin. This is known as the “no boundary condition” of space-time. That is to say that although it is believed that the entire universe originated from a point of singularity and appears to be expanding forever, at any point in time, space is finite. Spatial infinity is therefore a concept that is directly related to the passage of time.

Hawking explains that the speed of light is a very good demonstration of the concept of infinity. Although the speed of light is measurable and finite, “it would take an infinite amount of energy to accelerate an object with mass to 100% light speed. Because mass contributes to an object's inertia (resistance to acceleration), adding a fixed amount of energy has less of an effect as the object moves faster. This effect is only significant to objects moving at speeds close to the speed of light. At 10 per cent of the speed of light, if it takes only 0.5 per cent more energy than normal to achieve a given change in velocity, at 90 per cent of the speed of light it would take twice as much energy to produce the same change. As an object approaches the speed of light, its inertia rises ever more quickly, so it takes more and more energy to speed it up by smaller and smaller amounts. It cannot therefore reach the speed of light because it would take an infinite amount of energy to get there." (Hawking, 1998, 21). The speed of light, although measurable and finite, is for all intents and purposes infinite, and light itself is the most readily observable instance of infinity.

Directly related to the notion of infinity as defined by Hawking, Einstein's theory of relativity deals with the nature of the progression of time. Depending on the relative motion of observers and the strength of the local gravitational field, Einstein wrote that time can progress with different speeds. In particular, time effectively stops for objects traveling at the speed of light, but just as nothing can travel faster than light, time will not run backwards. Physicists call this phenomenon the *arrow of time*.

A difficulty with the *arrow of time* is that it is only observable in theory. For example, Maxwells laws of electromagnetism which describe propagation of electromagnetic waves including light, allow for solutions in which time runs backwards as well as forward. In reality, we can only observe those in which time runs forward; that is to say that all of the light we see comes to us from the past, and none from events that have not yet taken place.

So far, the most successful effort to explain the direction of time comes from thermodynamics. This area of physics attempts to explain the direction of time by analyzing the level of order and chaos in physical systems. If an isolated object changes its physical state on its own, it is much more likely that the next state will be less orderly than the previous one. If a crystal vase is dropped onto a concrete surface, it will shatter into thousands of pieces. Even though the vase will shatter predictably according to the laws of motion, the fragments of crystal will not spontaneously reconstitute into a vase from the floor, despite the fact that the formulas describing the catastrophic event are reversible. The 19th-century physicist Ludwig Boltzmann proposed an explanation of this thermodynamic arrow of time based on probability of all configurations of atoms that constitute a physical body. Of all possible configurations, there are significantly more of those that appear to us as disorderly, than those that appear orderly. Boltzmann thus provided a probable explanation of the second law of thermodynamics stating that entropy, or the measurable disorder of an isolated system, can only increase.

Figure 8 Slowing Time (Goge, 2011)

Einstein's general theory of relativity describes another space-time phenomenon called *time dilation*. Time dilation is a discrepancy between elapsed time measurements taken by observers either moving relative to each other or differently situated from gravitational masses. As an object approaches the speed of light, time relative to that object actually slows down. At the speed of light, time ceases to advance completely. According to Astronaut Ed Lu, these effects, although minuscule, are present when circumnavigating the earth in space on the International Space Station. When traveling in space at 28,968 kilometers per hour, over the span of six months, time is dilated by 0.007 seconds relative to the advance of time on earth. This means that astronauts are 0.007 seconds younger when they return to earth than they would be if they had remained on earth for six months. If an astronaut were to circumnavigate the earth at the speed of light for one hundred years, the individual would experience no advance in time, and would return to earth the same age as he or she was at launch. Time on earth however would have continued to advance, and one-hundred years would have elapsed. According to Einstein's famous mathematical equation for entropy: e=mc2, the energy requirements to completely stop time become infinite and unavailable, and traveling through space-time to the future will remain in the realm science fiction.

Chapter Four: Light, A Catalyst for Exploration

Scientists have pondered the nature of light for millennia, and have created many different forms of artificial light. Several such technologies include the electric light bulb, invented in 1880, the motion picture following five years later, and the discovery of neon and later florescent light in the early twentieth century. Scientific discoveries following the 1950s resulted in some technologies that are of great interest in more recent Lumino-Kinetic art explorations, including the laser and the computer (Bellis, n.d.). Because technologies that afford artists with new modes of expression are dependent on advances made in various scientific fields, many argue that art and science are interdependent. Isaac Asimov wrote about this relationship in his book, *The Roving Mind*:

"How often people speak of art and science as though they were two entirely different things, with no interconnection…That is all wrong. True artists are quite rational as well as imaginative and know what they are doing; if they do not, their art suffers. True scientists are quite imaginative as well as rational, and sometimes leap to solutions where 7878reason can follow only slowly; if they do not, their science suffers."

Running parallel to the technological discoveries of scientists, artists of this period were making discoveries of their own. Artists were not only finding ways to represent the idea of light, but also using light in their works. Predating the use of light as an artistic medium, there were many artists who were occupied with solving the very complex problem of how to represent light with paint.

Monet was busy observing and recording the various qualities of light and its interaction with form at various times of day. In his famous Haystacks series, Monet used paint pigment to represent the mirage-like illumination around haystacks in a field. Monet recognized the oscillation of form brought on by this aura of light, suggesting this through his technique of painting many discontinuous waves that appeared to ripple around the haystacks and through the surrounding landscape. Within the 1890s, a Scottish physicist and mathematician was developing his own scientific theories to explain the very nature of light. James Clerk Maxwell developed a number of mathematical equations and conjectures, which supported discoveries made by other scientists and proved that light had wave-like properties (Roberts, 2008).

Scientists soon realized however, that the wave model for light was inadequate, and did not explain certain properties of light. Einstein shook the scientific world with his demonstration of the photoelectric effect in which he proposed that light was composed of tiny particles of matter called photons.

Pre-dating Einstein's publications about the photoelectric effect by approximately twenty years, Seurat was working with painting techniques that divided light and colour into an array of pixels or particles, the sum of which created an image with an abundance of tones and values when viewed from an appropriate distance.

Figure 9 Seurat, Sunday afternoon on the Island of La Grande Jatte (Seurat, 1884)

Seurat was interested in the science of optics as well as how colors and values of light could be mixed in the viewer's eye (Roberts, 2008).

In an effort to settle an argument about the nature of a horse's gait, Eadweard Muybridge invented the motion picture in 1879 (Bellis, n.d.). Up until this time, it was commonly believed that when a horse galloped it would have at least one hoof still on the ground. Muybridge used a series of cameras along a horse–race track to capture twenty–four sequential static images. He then affixed these images to a rotating glass disc, which allowed the images to be viewed in rapid succession and demonstrated the true nature of the horse's gallop (Kingston Museum and Heritage Services, & Kingston University, n.d.).

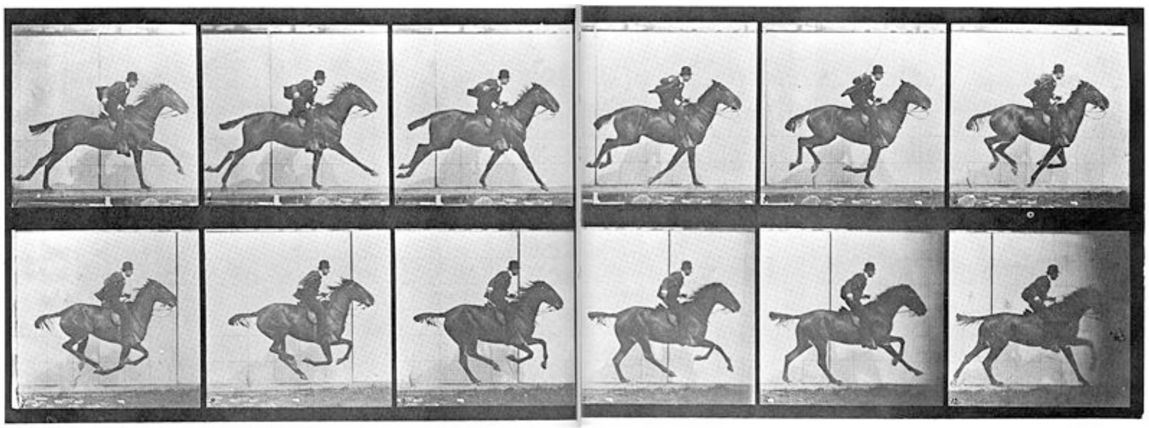

Figure 10 Muybridge Horse Race (Muybridge, 1904)

Muybridge certainly settled the dispute, but more significantly in doing so he invented a new technology. His invention, called the zoopraxiscope, is considered the first movie projector, and could be described as the first merger of light with motion to produce a two–dimensional kinetic light system.

As technology and science advanced, artists developed more sophisticated methods of exploring movement and light. While artists of the earlier periods of modern art were concerned with portraying movement within the artwork from a single vantage point, the Cubists of the early 20th century were very interested in movement, but not in the traditional sense. Cubism was more concerned with the movement of the viewer’s own vantage point, while depicting an object, person, or space from as many different surfaces as possible. Picasso, Braque, and later Juan Gris were able to reduce multiple vantage points associated with three-dimensional objects and space to a two dimensional pictorial plane (Popper, & Bann, 1968, 37-39).

Orphism was a short-lived artistic movement stemming from Cubism. Delaunay was considered the pioneer of this movement, and his research was primarily concerned with colour and chromatic light. In an abstract fashion similar to Cubism, Delaunay was producing work that demonstrated a correlation between light, colour, and movement (Popper, & Bann, 1968, 40). Delaunay was interested in the use of colour to imply rhythm, form, and space, employing a number of interesting ideas stemming from the colour theories of the time. He believed that colour interactions produced rhythms and that using complementary colours implied slow rhythmic transitions, while dissonant colours implied rapid vibration (Popper, & Bann, 1968, 42).

Futurism, another movement that was inspired by Cubism, was interested in the dynamism of modern life. Boccioni, a key figure in the Futurist movement, is credited with discovering the artistic equivalent of speed and movement (Popper, & Bann, 1968, 43). Boccioni's work "Dynamism of a Cyclist", 1913, indicates the movement and energy of a cyclist pedaling rapidly across time and space (Janson, Davies, & Janson, 2004, 815). Boccioni's famous 1913 sculpture "Unique Forms of Continuity in Space" was an attempt to reproduce not the movement of a running human figure, but rather the movement of the atmosphere surrounding the figure (Janson, Davies, & Janson, 2004, 871). During this time, Marcel Duchamp was also producing works that attempted to demonstrate movement in successive phases. Duchamp described his own 1912 painting "Nude Descending a Staircase, No 2" as an "Organization of kinetic elements—an expression of time and space through the abstract presentation of movement" (Popper, & Bann, 1968, 56).

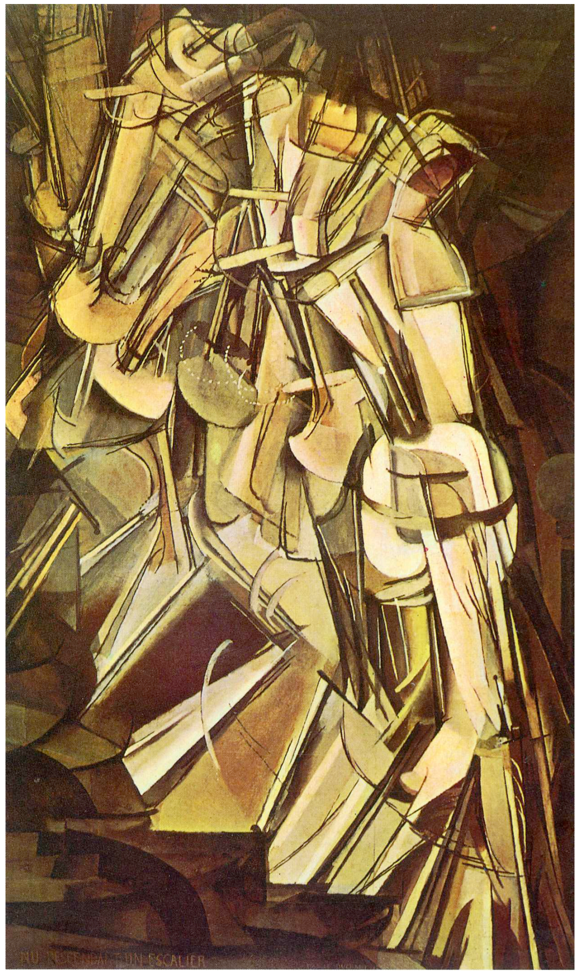

Figure 11 Duchamp, Nude Descending a Staircase, No 2 (Duchamp, 1912)

Artists working in the two-dimensional realm during the late nineteenth and early twentieth centuries had focused on depicting motion and light in a variety of ways, and eventually, a number of these artists moved on to explore motion in three-dimensions. The exploration of motion using sculptural forms led to the birth of kinetic sculpture.

Figure 12 Duchamp, Bicycle Wheel (Duchamp, 1913)

Marcel Duchamp was the first ever to create a kinetic sculpture with his 1913 piece entitled “Bicycle Wheel”. In the tradition of the “ready-made” object whereby mundane non-art objects were appropriated into art institutions and elevated to the status of fine art, Duchamp affixed a bicycle wheel to the top of a stool. Although the object was intended to be a comical piece, Duchamp was concerned with the juxtaposition of the static stool, implying a body at rest and the spinning bicycle wheel, implying a body in motion (Popper, & Bann, 1968, 123). Duchamp carried on with his experiments using ready-made objects in a variety of ways and eventually began creating more abstract spatial constructions, with his 1925 “Rotative Demi-Sphere” being of particular importance (Popper, & Bann, 1968, 122). Duchamp rendered a number of progressively growing circles aligned in an off centre manner onto a larger disc. When the disc was turned, the circles created the illusion of an ever-changing spiral (Popper, & Bann, 1968, 124).

The “Clavilux”, 1919, is another very intriguing discovery of this time. Thomas Wilfred, who had most likely been inspired by the colour organs built in the mid to late eighteenth century, invented a way to create kinetic visualizations of sound using light. Although Luis-Bertrand Castel had been experimenting with this idea almost 150 years before Wilfred’s time, Castel was limited by the available technology (Popper, & Bann, 1968, 156-157). Electric light had not yet been invented, and candlelight, which Castel’s system used, was simply not bright enough. Working from Castel’s concept, Wilfred perfected the idea, and a Lumia system was permanently installed at the Lumia Theatre in New York, making its public debut in 1922 (Popper, & Bann, 1968, 161-162), (Weibel, & Jansen, 2006, 426). The system consisted of a keyboard, which controlled a series of mirrors and reflectors, which in turn controlled light from 32 independent projectors. Performances were composed much in the same way that music is (Weibel,& Jansen, 2006, 426). The movement and colour of light were arranged in sequences to evoke images that referred to the world, emotion, or as purely abstract patterns that appeared as kinetic interpretations of numerical sequences and geometric shapes.

In the 1920s, Alexander Archipenko was predominantly interested in demonstrating motion and change, and regarded subject matter as somewhat inconsequential (Popper, & Bann, 1968, 123). Archipenko was creating machines intended to evoke the illusion of movement in pictorial space but using mechanical systems of horizontal metal bands, which turned along a horizontal axis. Although Archipenko considered himself the pioneer of movement in the three-dimensional arts, his works were more concerned with the exploration of movement on the picture plane (Popper, & Bann, 1968, 123).

The Russian Constructivists began exploring movement in a different way. Brothers Naum Gabo and Antoine Pevsner reflected on the notion of real movement in art and summarized their thoughts in the Realistic Manifesto, published August 5th, 1920. The manifesto "announced the existence of a new element, kinetic rhythm which is to be the basis of a new perception of real time" (Popper, & Bann, 1968, 124). Gabo, Pevsner, Tatlin, and several other constructivist artists went on to produce kinetic works that explored a variety of simple mechanical systems. Of particular importance are the explorations of Gabo, involving the creation of illusory volumes of space using rapidly rotating components set into rhythmic vibrations (Popper, & Bann, 1968, 125).

Laszlo Moholy-Nagy, inspired by Gabo's works and theories, began his own explorations, and in 1922, published with Alfred Kemeny his own manifesto on the system of dynamico-constructive forms (Popper, & Bann, 1968, 125). Moholy-Nagy proclaimed, "Constructivism represented the activation of space by means of a dynamico-constructive system of forces", and declared that "the static principle of classical art should be replaced with the dynamic principle of universal art" (Popper, & Bann, 1968, 125). Moholy-Nagy was interested in exploring the relationship between man, materials, force, and space, and began researching ways in which to activate space with light and movement. After some experimentation, Moholy-Nagy completed his piece entitled "Lichtrequisit einer Elektrischen Bühne" (Light prop for an electric stage) and exhibited it in Paris in 1930 (Popper, & Bann, 1968, 125).

The work was an assemblage of a variety of different metallic surfaces, textures, and shapes formatted in a quasi-synthetic cubist and constructivist style atop a rotating surface.

Figure 13 Moholy-Nagy’s Lichtrequisit einer Elektrischen Bühne (Moholy-Nagy, 1930)

The piece was placed in the gallery space, and lights were shone on it from various angles, resulting in a countless array of moving light patterns and shapes on the gallery surfaces. The artwork was a demonstration of the ability of a sculpture to manipulate light and concurrently its environment. “Lichtrequisit einer Elektrischen Bühn” is considered the first sculpture to explore the relationship between light and movement, earning Moholy-Nagy credit as the father of the Lumino-Kinetic movement (Popper, & Bann, 1968, 125).

American artist Alexander Calder, like Moholy-Nagy, was particularly interested in the dynamic relationship between artworks and environment as well, but rather than allowing the artwork to manipulate the surrounding environment, Calder used the environment to modulate the movement of his works. In 1930, Calder was experimenting with relationships between air currents and movement. Calder demonstrated this movement in his works by allowing air currents to directly influence them. He is credited with the invention of the Mobile, a term coined by Duchamp after viewing two of Calder's pieces in 1932 (Popper, & Bann, 1968, 145).

Light: The principal medium

Although Moholy Nagy is credited with creating the first Lumino-Kinetic art work (Popper, & Bann, 1968, 125), the most important breakthroughs in the movement were not made until the 1950s. Developments in material science made a variety of fascinating light-conductive and reflective materials available that did not exist at the time of the first artistic experiments with light.

Frank Malina, one of the first artists in this field to experiment with a variety of materials and light sources, was particularly interested in the Moiré effect (the perceived movement that occurs when simple mathematically derived patterns printed on translucent material are superimposed on one another) (Weibel, & Jansen, 2006, 428). He produced a number of kinetic paintings based on the effect, which he called his Lumodyne series (Popper, & Bann, 1968, 166). Colour transformations and movement on a screen were informed by backlit mechanical systems. Victor Vasarely was able to create the illusion of movement on a two-dimensional surface without the aid of mechanical systems by manipulating the eye's perception of tonal values. The pieces were so effective that Vasarely is now regarded as the father of Optical art, an artistic movement notably concerned with the creation of illusory spaces and movement and the viewer's perception of these phenomena (Popper, & Bann, 1968, 101)

In the 1960s, a number of artists were experimenting with the interaction between light and material. Among leading figures, the work of Gerhard von Gravenitz is notable. Gravenitz was producing shadowbox reliefs that contained numerous mirror fragments that rotated along an axis perpendicular to the picture plane. A light source was focused in a beam across the rotating mirror surfaces, and a highly effective display of kinetic light was produced that in many cases escaped the confines of the shadowbox and projected into the gallery space (Weibel, & Jansen, 2006, 230). Working on similar ideas at about the same time, Alberto Biasi was producing his Light Prism works. Biasi's light prism pieces were constructed much in the same way Gravenitz's works were, although rather than using an array of mirrors, Biasi used optical prisms (Weibel, & Jansen, 2006, 246-247). Whereas Gravenitz was interested in directing light through his piece as a beam, with the mirrors constantly reconfiguring the beam's path to show movement, Biasi was interested in the deconstruction of the beam itself. Using a simple array of rotating prisms, Biasi was able to demonstrate how light can be broken down and reconfigured to produce a variety of movements, tonal values and colours (Weibel, & Jansen, 2006, 246-247).

From 1900 to 1930, scientists were developing fluorescent light as an alternative to incandescent light. Incandescent bulbs produced a lot of heat, were unreliable, and were highly inefficient. It was not until the 1960s that the florescent light was perfected and was used as an artistic medium (Weibel, & Jansen, 2006, 528). After mounting a florescent tube to his studio wall, Dan Flavin was inspired by what he called "the merry and restless image of gas" (Weibel, & Jansen, 2006, 528). Flavin began using the florescent tube in his minimalist works as an "expression of line transposed into light" (Weibel, & Jansen, 2006, 528).

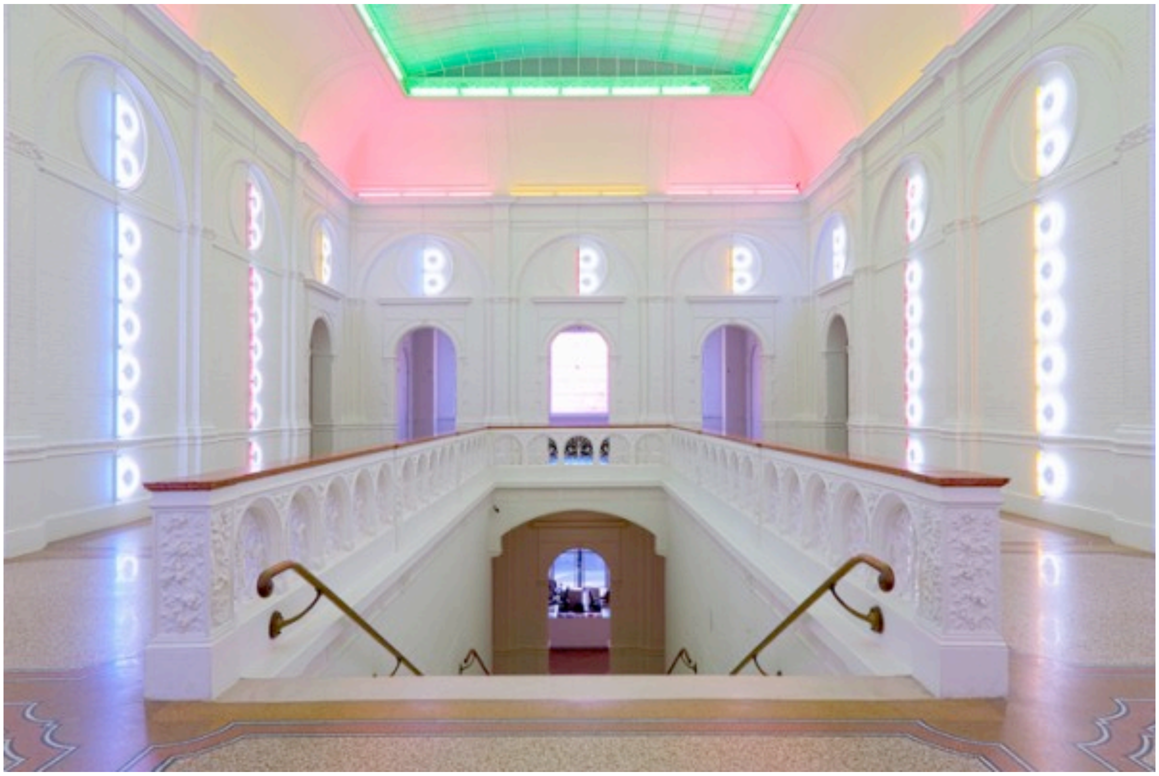

Figure 14 Dan Flavin, untitled (to Piet Mondrian through his preferred colors, red, yellow and blue) (Flavin, 1986)

Flavin was particularly interested in the viewer's perception of the interaction between light and space, creating installations that evoked a sense of rhythm and space. Although Flavin's work did not literally demonstrate movement, it can be argued that the visual rhythms that Flavin created evoked a sense of movement and time.

American artist James Turrell began producing light works in 1968 and, like Flavin, he was concerned with the perception of light and space. Although Flavin and Turrell were developing similar ideas, Turrell hid his light sources from the viewer to create the ultimate illusion that light has a material presence. Spanning a variety of scales, Turrell's pieces range from simple projections of intense light that create the illusion of floating geometric forms to massive open spaces that appear to be divided by a plane of intense light (Collins, 2007, 260). In all cases, it could be argued that Turrell's works are kinetic. As the viewer approaches a piece, his or her perspective changes, and the floating geometric forms, which appeared to be perfect from a distance, appear to change. Similarly, Turrell's large installations sometimes challenge viewer's perception by attempting to deny the viewer access to a space. Turrell's large room installation works appear to be flat and two-dimensional planar surfaces, but from the correct vantage point they morph into three-dimensional voids of space, which are actually physically accessible to the viewer (Collins, 2007, 260).

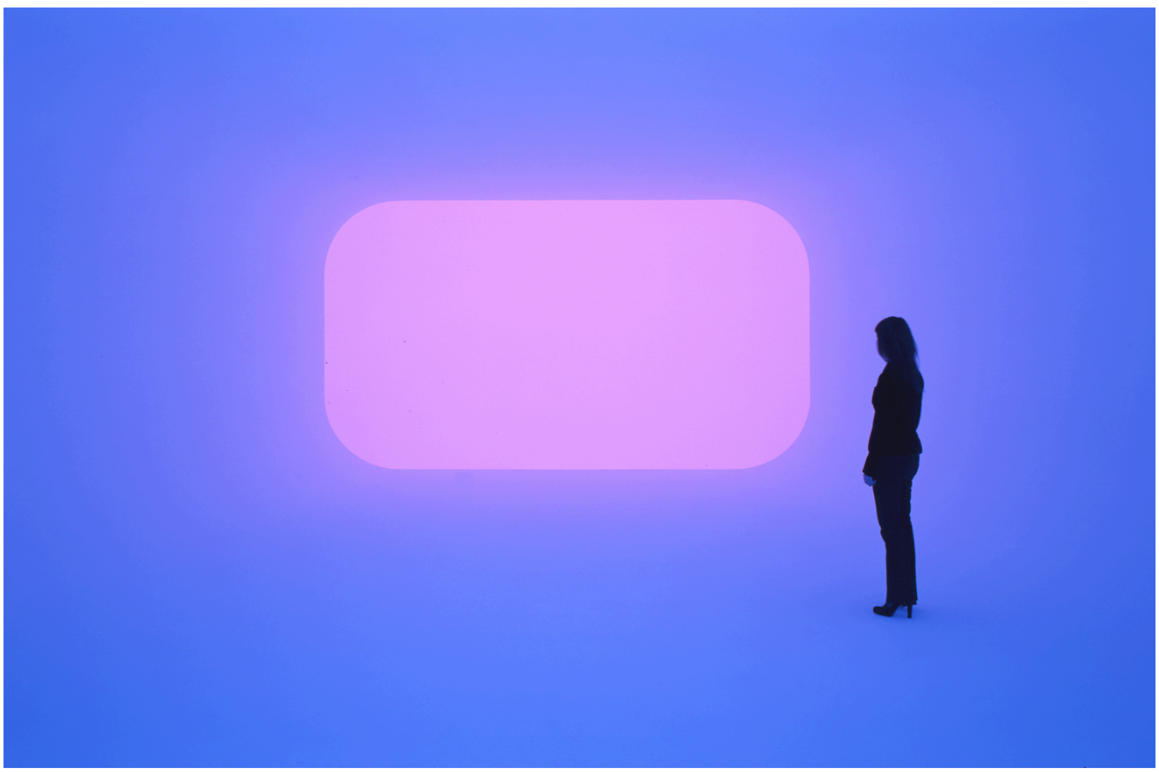

Figure 15 James Turrell, Dhatu 2010 (Turrell, 2010)

Laser: The Fundamental Articulation of Light, Space, Movement and Time

Constantin Brancusi's "Bird in Space" was an effort to capture the essence of a bird in flight. The form was a radical departure from traditional representational approaches, and was concerned with reducing the idea of a bird in flight to its essential components. Brancusi's work so ambiguously depicts a bird in flight that it can even be considered a

Figure 16 Constantin Brancusi, Bird in Space (Brancusi, 1923)

metaphor for the pure notion of movement, allowing us to feel rhythms subconsciously and experience movement in a static object. Flavin revisited Brancusi's ideas, producing an homage to Brancusi's "Bird in Space" entitled "Diagonal of Personal Ecstasy (the

Diagonal of May 25, 1963)". Working with a single fluorescent light tube, Flavin's rendition was a minimalist representation of a bird's flight path through the air. Flavin explained the use of the fluorescent tube in his minimalist works as an "expression of line transposed into light" (Weibel, & Jansen, 2006, 528). Gone were Brancusi's graceful soaring lines and delicate balance of mass and geometric form in three dimensional space; for Flavin, the most fundamental way to articulate a space between two points is with a line on a two dimensional surface. Also absent was the elegant curvature that suggested the trajectory of flight; Flavin reduced this by affixing the fluorescent tube to the gallery wall at a 45-degree angle.

Figure 17 Dan Flavin, Diagonal of Personal Ecstasy (Flavin, 1963)

“[Art] first of all is optical. That’s where the material of our art is: in what our eyes think.” In light of this, the very medium that Flavin used demonstrated form and space could be reduced to light, and movement to line.

Flavin was limited by the technologies of his time, and although he was concerned with the use of light to create line, he was unable to accomplish this in the purest sense– this is why the fluorescent tube was used as an “expression” of line transposed to light rather than light itself. Although Flavin was using light to articulate form, he was unable to escape the fact that the physical components used for light making were also inherently part of the work. Despite Flavin’s massive success as a minimalist artist, his work was dismissed on numerous occasions as being nothing more than a commercial display of light fixtures.

The laser is a product of science, and has furnished the lumino-kinetic artist with the ability to articulate space, light and time. The focused beam of light produced by the laser is a pure demonstration of light as line in space, but perhaps more importantly serves as a metaphor for the linear passage of time. On May 16, 1960, Theodore Maiman operated the first functioning laser at Hughes Research Laboratories in Malibu, California (Garwin, & Lincoln, n.d.) The initial examples of the laser were highly experimental, and were not readily accessible to artists; perhaps had it been more readily available, It would have been Flavin's medium of choice. It was not until the late 1960s and early 1970s that scientists began collaborating with artists to explore the technology in creative ways.

In the mid-1960s, Lowell Cross, a fine art graduate student at the University of Toronto, began experimenting with music visualization using televisions and radio frequency modulators. In 1969, Cross and laser physicist Carson Jeffries of the University of California at Berkeley collaborated on a visual project. Using a laser, they created visualizations of sound and music at Mills College in Oakland, California. Their work was an extension of Wilfred's clavilux explorations, but using more contemporary technologies.

During the late 1960s, a sculptor named Rockne Krebs purchased a helium-neon gas laser; working at the University of Maryland, he designed an exhibit consisting of one laser and two mirrors. Kreb’s work was so well received that he was commissioned to work with Hewlett-Packard scientists on a display for the six-month-long 1970 World Fair near Osaka, Japan. The 1970 event drew an enormous number of artists and scientists interested in the emergence of the fantastic new laser technology, and inspired the formation of in interdisciplinary artist/scientist group called "Experiments in Art and Technology", or E.A.T. for short. Members of the E.A.T. collective were interested in exhibiting optical experiments produced by artist-scientist collaborations. E.A.T. later worked to create an installation at the Pepsi Pavilion located at the World Fair, and commissioned Cross and Jeffries to work together to design a massive-scale, clavilux inspired laser performance.

Around the same time, a post-doctoral student at California Institute of Technology named Elsa Garmire began experimenting with ways to use lasers to bring art and technology together. Garmire received her doctorate at MIT, studying laser physics, and during her post-doctorate work, found that her research had become stalled. Looking for intuitive reactions that would help resolve her research dilemma, she began experimenting with the laser in ways that she believed a “pure artist” would.

In 1969, Garmire created a laser light “wall” that participants could walk through, as part of Caltech’s celebrations of the first lunar landing. She later used a laser outdoors to create a massive light performance from the top of the campus library. Inspired by

Malina, Garmire began experimenting with the reflective and refractive qualities of a variety of materials, and found that she could produce very interesting abstract projections through plates of glass with bubbles of dried contact cement. Garmire's minimalist experiments attracted the interest of E.A.T., and Garmire spoke at a conference at the University of Southern California in November 1970. At the conference, film-maker Ivan Dryer took a keen interest in Garmire's work, and set out to visit her studio/laboratory to create a film documentation. After observing the brilliant patterns and intensely saturated colours on the wall, he realized that film could not adequately capture the experience of the laser performance, and was immediately convinced that a live laser performance would be better than any conventional motion picture.

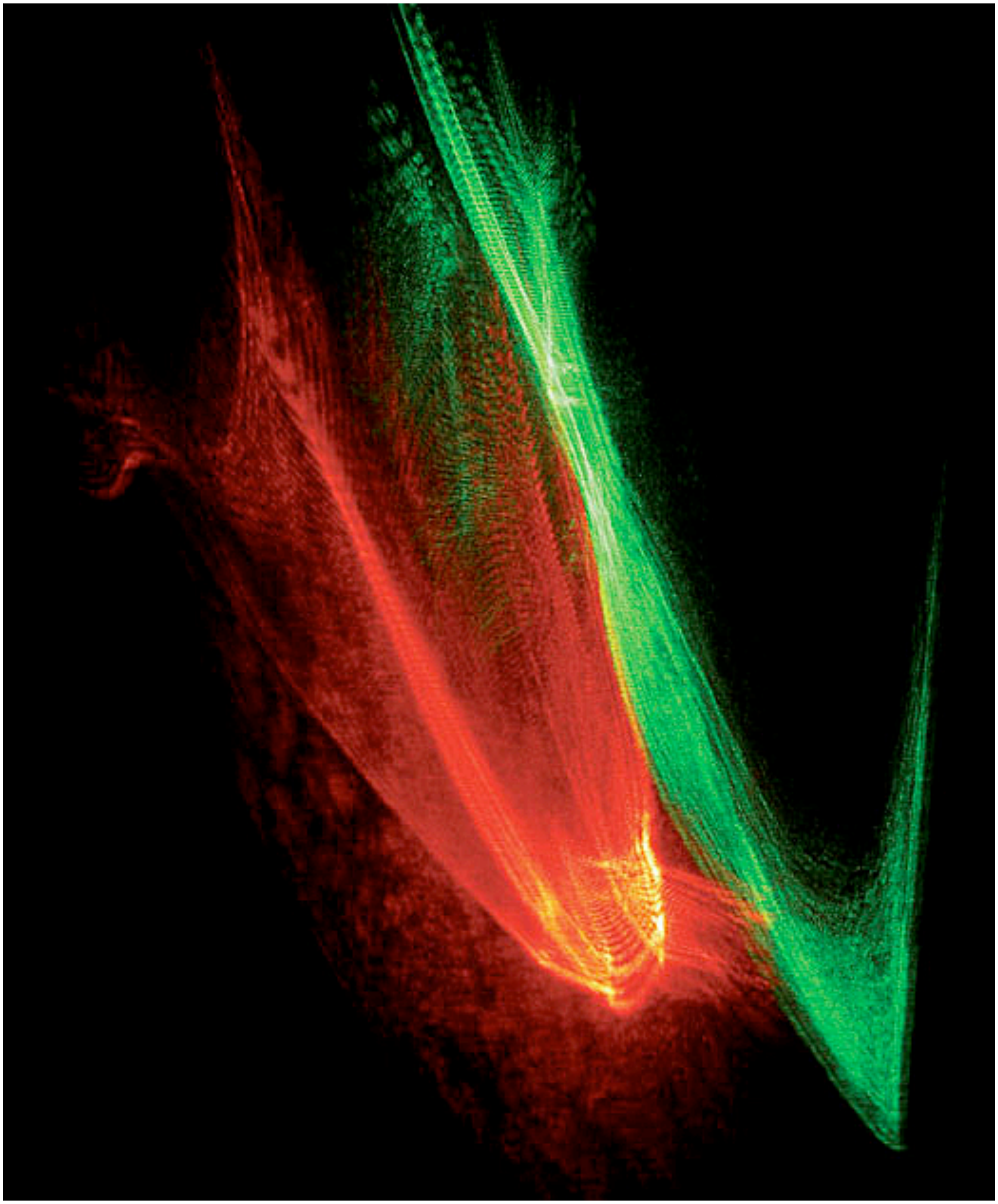

Figure 18 Elsa Garmire's Dried Contact Cement Patterns (Garmire, 1970)

Dryer had been an astronomy major at university, and had volunteered sporadically as a guide at a public science centre in Los Angeles, called Griffith Observatory. Dryer worked with Garmire and her hand made glass lumire plates, and prepared a demonstration show for Grifith Observatory officials of an “undulating, kind of organic image among the stars.” The duo called the show “Laserium”, or “House of the Lasers”.

In 2003, a group of artists formed a collective called the United Visual Artists (UVA). The UVA produces works that are concerned with the intersection of sculpture, architecture, live performance, moving image, and digital installation, and they have produced a variety of interactive sculptures and installations whose primary medium is laser light. UVA’s installation The “Speed of Light”,

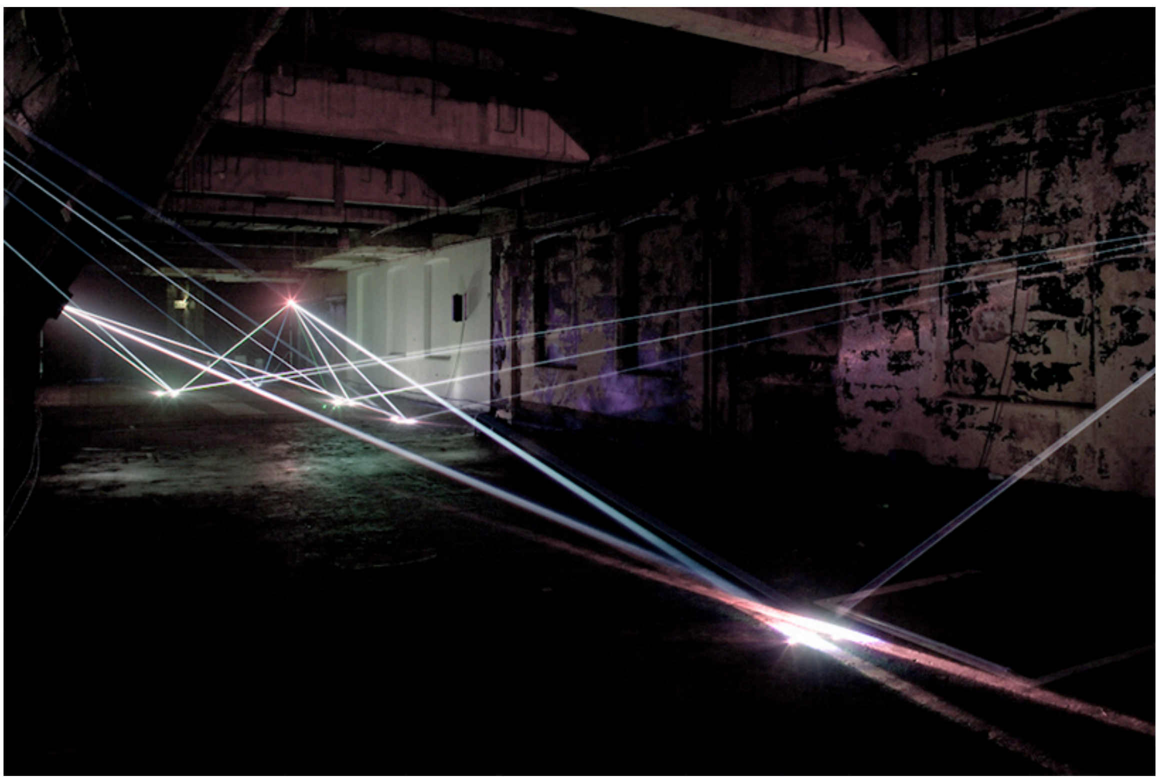

Figure 19 UVA, Speed of Light (UVA, 2010)

produced in 2010 for Virgin Media, was an intensely active piece that reacted to pre-recorded sounds and the movement of the audience throughout the space. In this piece, UVA intended to demonstrate that speed, movement, and light are universally the same.

Experimental laser technology has progressed to where it is now possible to create holographic images in free air. In February 2006, the Japanese National Institute of Advanced Industrial Science and Technology (AIST) collaborated with Keio University and Burton Inc. to produce a laser device capable of projecting three-dimensional images into empty space. The projections consist of dot arrays, and although fairly rudimentary, this technology will certainly be of interest to artists working in the realm of kinetic light art.

Chapter Five: An Evolving Fascination

For as long as I can remember, I have had a fascination with the way things work; in fact, one of the first books that I recall owning was David Macaulay's "*The Way Things Work*". Macaulay's book explored simple mechanical systems through a variety of comical situations with cartoon wooly mammoths. From staple guns to printers, the book offered an explanation of the inner workings of machines that otherwise appeared to me to work magically. For the first few years of grade-school, I carried the 384 page hardcover book everywhere. I studied the book meticulously during school lunch hours and the bus ride home. The writings inspired me to explore and ask questions about the workings of various household items. On occasion I was motivated to disassemble toasters, blenders, telephones and mechanical pens; however, to my parents' dismay I was not always able to recall how to reassemble them. Nonetheless, my parents understood my ways, and never got mad at me. Soon after they realized that I seemed to have an interest in this sort of thing, they would bring things home for me to take apart, and challenge me to put them back together.

My parents enrolled me in a youth development program called "4H", where I learned to service, repair and restore small engines and other mechanical systems. As I explored mechanical devices, I discovered that although they appeared complicated, they could be understood as a series of simple components working in unison to achieve a complex task. Finely tuning the various components to work with one another would result in flawless operation, while tweaking one component too much would result in catastrophic failure. Another critical factor in my developing interest in mechanical systems was the study of music. My parents enrolled me in piano lessons, and although I never mastered playing the piano, I did learn to read and write musical notation. I soon realized a strong parallel existed between the rhythmic patterns in music, and the mechanical patterns of movement in machines. The small engines and machines that I restored resembled concert orchestras; each component contributing to a coordinated symphony of combustion, kinetic movement and exhaust fumes. I continued to explore music, playing various instruments– including the bass guitar and tenor saxophone, and began to understand the world as Einstein said– musically.

In my first years as an undergraduate student at the University of Calgary, I had the opportunity to take electives in Geology, Astronomy, and Anthropology. These courses introduced new concepts to me, but also confirmed the rhythmic nature of things that I had suspected. Furthermore, the rhythms and patterns present in cellular functions, the various ecological systems on earth, and the birth and death of stars are all kindred. Although I was interested in understanding the operation of the various systems within and beyond the world, I became fascinated with exploring the recursive relationship of these systems. Before long, I was looking for ways to articulate this "recursiveness" visually.

A particular sculpture class introduced two fitting visual parallels that I was looking for: tessellations and fractals. A tessellation is the systematic tiling of two dimensional space using one or more geometric shapes, called tiles, with no overlaps and no gaps. A fractal system is "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole" (Mandelbrot, 1983).

Through sculpture, I discovered ways to explore and express these systems in ways that related to my interest in the physical and rhythmic structure of things. As I studied tesselations and fractals, I began exploring ways to express them mathematically as numerical patterns and simple algebraic relationships. Mathematics is powerful, elegant, and essential to the way that we describe everything from the quantum scale to the astronomical. It is the universal language; the fundamental access point to the architecture of everything. According to American theoretical physicist Richard

Feynman, in order to learn about and appreciate nature, "...it is necessary to understand the language that she speaks in."

I found that understanding these systems as mathematical constructs allowed me to access and understand them in a musical way, as music itself is essentially a mathematically derived system. Using mathematics, I could create proportion and pattern that were controlled by a limited set of variables inspired by the rhythms and harmonies present within and beyond the world. I became interested in articulating these systems through constructivist sculptural practices, setting up mathematically derived and controlled relationships between each component within a construction. Each construction was a metaphor for the relationship between a complex system and its numerous simple components– a sculptural parallel to the recursive and rhythmic architecture that seems to govern everything.

Following my undergraduate studies, I entered the Southern Alberta Institute of Technology's Machinist Technician program. The program provided me with the technical skills required to create sculptural forms with mathematically absolute dimensions. From a conceptual point of view, machinist procedures and tools allow dimensional and proportionate relationships to be controlled to a high degree of accuracy. Such control allows the produced work to exist almost purely as a physical analog of a mathematical system. Additionally, the program unveiled opportunities for sculpture forms that were impossible to produce with conventional sculpting techniques.

The following year, I studied industrial design at the Academy of Art University, in San Francisco, California. Of particular interest to me were the design theory courses. The courses introduced a variety of design philosophies through case studies of numerous contemporary automotive, furniture, and product designers. French-Italian Automotive designer Ettore Bugatti believed that the pinnacle of fine design, and by extension, fine art, could be found not by adding elements, but by removing unnecessary ones. Jony Ive, the current senior vice president of design at Apple, also has a similar mandate; he wrote that "simplicity is not the absence of clutter, that's a consequence of simplicity. Simplicity is somehow essentially describing the purpose and place of an object and product. The absence of clutter is just a clutter-free product. That's not simple." At the time that I recorded these quotes in my notes, I had no idea that they would inspire and transform the fundamental premises of my own artistic concerns and practices.

Enter the MFA

When I entered the Master of Fine Art program, I was looking for ways to express and explore my fascination with the structures and rhythms of the world.

My research in my first semester lead me to create "Polar Curves". Inspired by my interest in the abstract analysis of natural systems, "Polar Curves" was an attempt to articulate my understanding of the mathematical human construct that we use to understand the world around us. Using square aluminum tubing, I created a three by three by six foot rectangular prism. Strands of electro-luminescent wire were stretched along the prisms length within the volume of space defined by the prism. The strands of wire were positioned relative to one another to produce mathematically derived curvature from a number of vantage points, relating to the Cartesian method of mapping linear curves, hence the work's title.

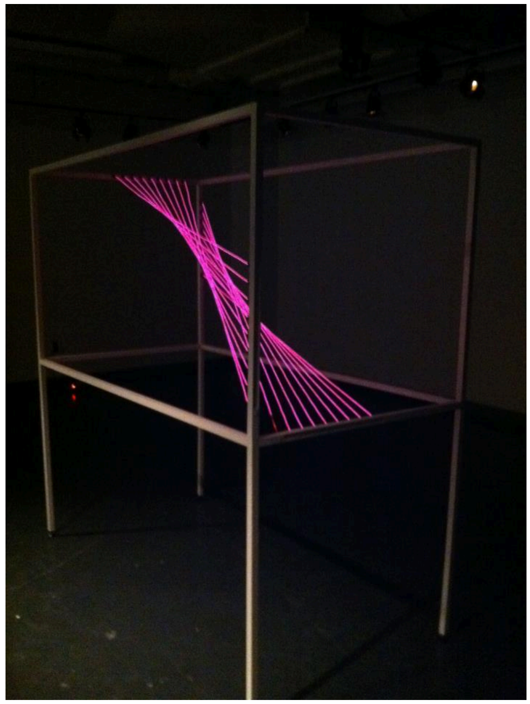

Figure 20 Polar Curves, 2011

The prism was intended to represent metaphorically the various rationales that we use to interpret our world, for example: science, technology, design, etc. The strands represented the various relationships that we define within the boundaries of rational thought. The curvatures defined by the strands collectively represented the beauty of natural phenomenon, in conjunction with the underlying architecture– the complicated relationships that must exist in order for natural phenomenon to exist.

Initial maquettes for the piece called for light-weight monofilament line, or small-gauge braided steel cable stretched within the boundaries of the prism. As the work developed, I was looking for ways to articulate the linear forms within the prism in a non-tactile way,

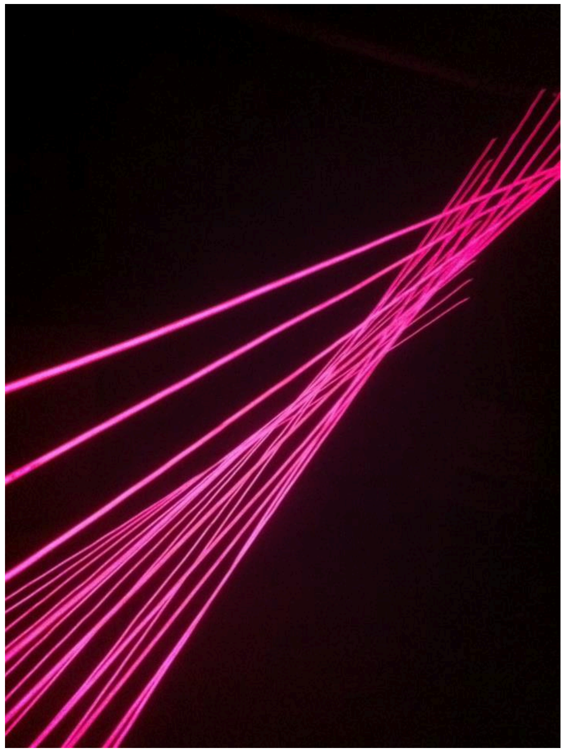

Figure 21 Detail of Polar Curves, 2011

or at least create the effect of an intangible presence. Because the strands represented linear rational thoughts and ideas, it was necessary to articulate them in as much of an intangible way as possible; an idea or thought is a mental construction, as much as the perception of light is. A thought rationalizing a phenomenon is as intangible as a beam of light, but both are capable of articulating the space between points of observation. My explorations led me to use the electroluminescent wire, which glowed a brilliant pink colour when an electric current was passed through it. The wire– a tactile object– was for the most part enveloped and hidden in brilliant light. Laser would have been the ideal medium for this, but required technical expertise beyond my skill level.

Inspired by explorations during my first semester, I became fascinated with the phenomenal nature of light. It was at this time that I discovered Cezanne's quote, describing visual art as first and foremost an optical experience. Stemming from my interest in mechanical systems, and inspired by Cezanne's quote, I began experimenting with ways to create movement with light. The eyes are highly sensitive, and are capable of detecting the most minute changes in light and colour. The visual cortex is constantly processing and interpreting these changes, and as a result, we are able to perceive movement visually. Because light is fundamental to our perception of movement, it must be the essential expression of kinetic systems.

Experimenting with light projections using coloured light sources, I made a series of small light-conductive sculptures using borosilicate glass rods. The rods, approximately the size of ballpoint pens, were heated and bent into a variety of simple zigzags and kinked sections, and inserted into holes drilled in a piece of thick black nylon. In a moment of inspiration, I was viewing a music video over YouTube on my iPhone, and I set one of the glass rod sculptures on top of the screen. The screen projected the video image through the glass rods, and imparted a stunning visual experience of dancing vibrant colours and light. I was particularly intrigued with how the luminous flickers of colour reflected the tones of sound and musical rhythms coming from the phone. Inspired by the relationship between light, movement and sound, I began to work on my Winter semester project entitled "I hear what I see: I see what I hear" (ISWIH) The work was concerned with a particular manifestation of synaesthesia involving sound, colour and movement. Since colour and movement are visual components of light, it was fitting to explore synesthesia with a kinetic light system. Although true synesthesia cannot be experienced without a specific neurological condition; "ISWIH", was an attempt to simulate the effect.

Working with audio visual processing software, a visualization of sound from pre-recorded sources was produced. Harsh, abrupt sounds would produce explosions and flashes of colour and light, while soft rhythmic sounds would result in a display of flowing transformations of colour, saturation, and intensity. The resulting video feed was projected into a series of large acrylic rods, which were cut to lengths that corresponded to numerical values derived from musical scales and patterns. The projector and audio visual equipment were hidden from the viewers within a large base, and the acrylic rods were mounted on top. The viewers experienced kinetic light, suggestive of rhythms and tonal ranges corresponding to the muted sounds informing the work.

Conceptually, the piece functioned inversely to Thomas Wilfred's 1919 invention the "Clavilux". Wilfred's intention was to produce a visual equivalent to musical performances without direct association to sound, whereas my work attempted to demonstrate a connection between light and sound.

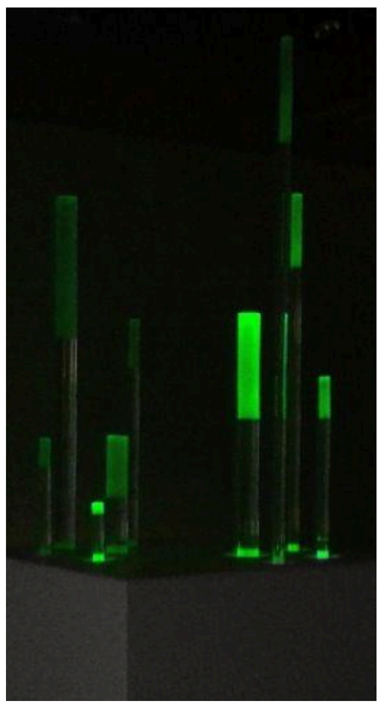

Figure 22 I hear what I see: I see what I hear, 2012

Artist Jonas Friedemann Heuer created a contemporary version of Wilfred's system in 2009 called the Clavilux 2000 (Heuer, n.d.). Unlike Wilfred's concept, Heuer's work was directly concerned with the crossing of auditory and visual senses. Clavilux 2000 directly translated live musical performances to kinetic light performances (Heuer, n.d.). Heuer's piece allowed the audience to experience the synergistic relationship between light and sound directly.

"ISWIH" explored the territory between Heur's Clavilux 2000 and Wilfred's Clavilux. Similar to Wilfred's work, my piece was presented to the audience in complete silence, but similar to Heur's work the light movement and colours were informed by a variety sounds within the base. The work's title, "I see what I hear : I hear what I see", in conjunction with the sound-informed lighting system challenged the audience to realize the relationship between light and sound without allowing access to the auditory component of the piece. My intention was to create an opportunity to experience internal mental projections of sound within the mind associated with the movement, brightness, and colour of the light within the work.

Realization

Thematic tradition is one of the underpinning elements in the history of art. There are numerous examples of artists paying tribute to an idea or theme by revisiting a pioneering artist's work and producing their own version. This exercise is a way of keeping a thematic tradition alive, while paying tribute to the work(s) of the preceding artist(s). More importantly, these types of works bring thematic traditions into contemporary contexts, allowing them to be affected by contemporary concerns and practices.

For my Spring semester directed study, I took the opportunity to research ways in which a laser could be used to articulate space and movement. My research was based on the evolution of minimalist expressions of movement and space, and in the spirit of thematic tradition, I decided to create a tribute both to Brancusi and to Flavin, and his own homage to Brancusi, "Diagonal of Personal Ecstasy (the Diagonal of May 25, 1963)". While

Brancusi's "Bird in Space" was an effort to capture the essence of a bird in flight as a sculptural form, Flavin managed to create an even more fundamental expression using practices that were unavailable to Brancusi. At the time, Flavin's fluorescent tubes were the ultimate "expression of line transposed into light" (Weibel, & Jansen, 2006, 528), and thus movement in space.

Working from the point where Flavin left off, I created an installation called "Bird in Finite Space: Infinite Flight". Using Flavin's "expression" of line transposed to light as a starting point, I set out to create an articulation of light as line in space using lasers, a medium that was unavailable to Flavin. The work was absolutely minimalist– an electric blue laser beam cutting through the void of space within the gallery, creating a triagonal line. While a diagonal line divides a two dimensional rectangular shape from one corner to the opposite, a triagonal is effectively the three dimensional equivalent. A triagonal connects opposite corners of a three dimensional form, while delineating the centre of the

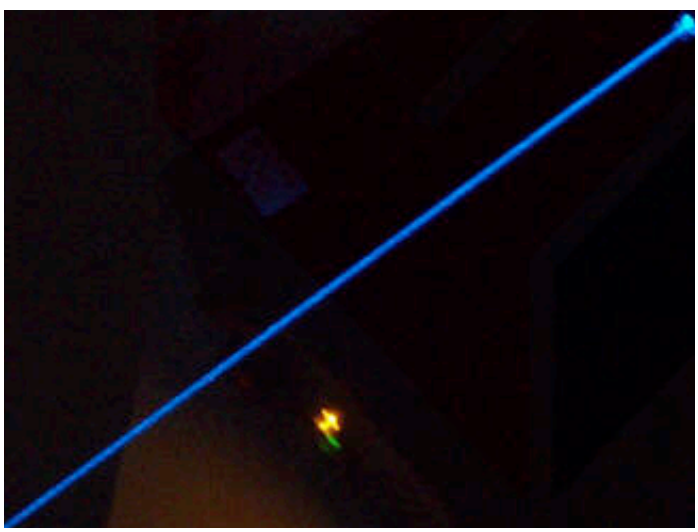

Figure 23 Bird in Finite Space: Infinite Flight

form's volume. In geometry, a triagonal holds all of the mathematical data required to define the absolute dimensions of a cuboid; it is the essential expression of cuboidal space.

The focused beam of light produced by the laser was a pure demonstration of light as line in space, and by extension, movement through space. In addition to thematic concerns surrounding the ultimate expression of a bird in flight, the work was an exploration of how the movement of light allows us to sense the passage of time, progression, and our perceptual awareness of rhythm and space. Ultimately, the installation served as a metaphor for the linear passage of time. Given the infinite nature of light, and the finite nature of the space in which the work was installed, the installation was intended to demonstrate infinite movement between two points in three-dimensional space, accounting for the work's title, "Bird in Finite Space: Infinite Flight". It also intended to demonstrate the intangible parallel between light and time and the infinite nature of both.

The work was thematically tied to Brancusi's original concerns, built on the minimalist concerns of Flavin, and explored additional thematic elements that could only arise with the use of contemporary technologies.

The Final Year

In the second year of the Masters program, I became increasingly interested in the use of laser light as the ultimate expression of movement, space and time and light itself. During the beginning of the second year, I read Stephen Hawking's book, *A Brief History of Time*. I was intrigued by the relationship between space, time, and the speed of light the fact that the further into the observable universe we look, the further back in time we are actually seeing.

It occurred to me that the further away we are able to see, the less certain the present of that space becomes, and the more speculative the "observations" become. What is defined as the "known universe" actually becomes more unknown in proportion to the distances between us and what is observed. I personally find this conflicting relationship to be absolutely sublime; the notion that our present is defined by our immediate surroundings, and yet even though the night sky is part of that immediate surrounding, it is a relic of the past and bears no resemblance to the reality of that space. Even our observations of the sun are in a constant state of past-tense (the reality of the sun is blocked by a space-time void). As a pure abstraction from this idea, our immediate surroundings are not represented in absolute real time either. Because it takes a finite amount of time for light to move through a finite amount of space, our visual perceptual awareness is always behind what is actually occurring; luckily, this differential is infinitely small, and for all intents and purposes, only exists within the realm of subatomic physics.

Working with these ideas, I made an installation for the winter semester called "As Far As We Know". I built a device capable of transforming an audio feed to laser movement, and an audio recording of Hawking's book, *A Brief History of Time*, was played endlessly through the work. As the audio played on, a beam of laser light transmitting from the device reverberated in space, much like a guitar string. The sculptural component of the installation was made to resemble a device for radar transmission, and reenforced the notion of light as a conduit for information.

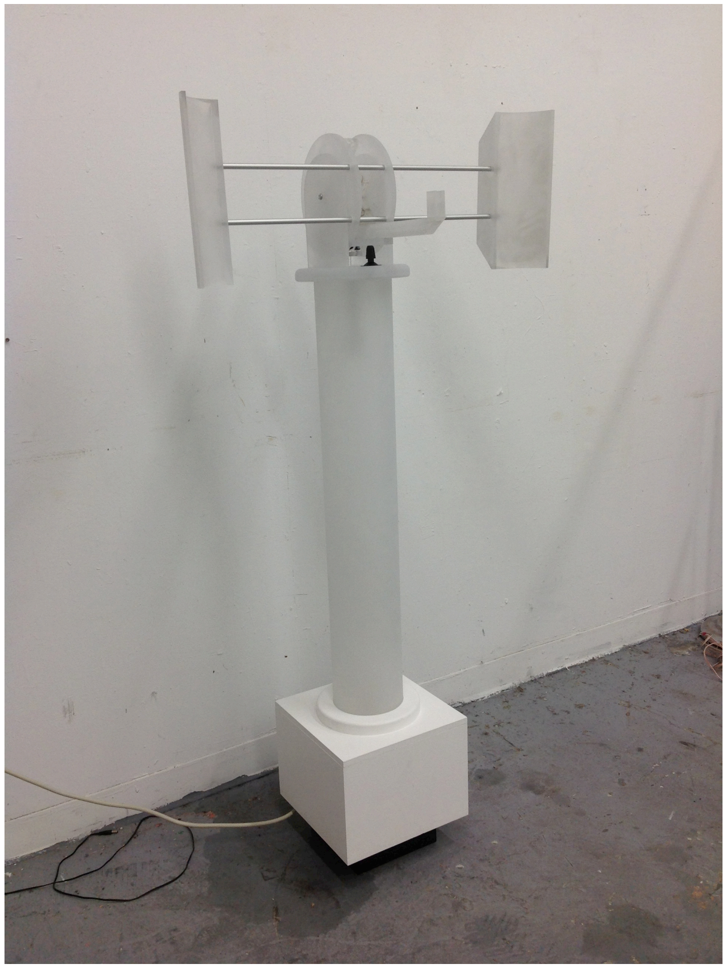

Figure 24 “As Far As We Know”, 2012

An interesting thing about the word “RADAR” is that it is palindromic, as the same forward or backward. The palindromic nature of the word parallels our constant state of reception and transmission of information. On a daily basis, we scan the sky for clues about the nature of our existence, while at the same time broadcasting information about our own existence into space. From the lights of our cities, our television signals, and radio broadcasts, we are constantly participating in an information exchange with the universe.

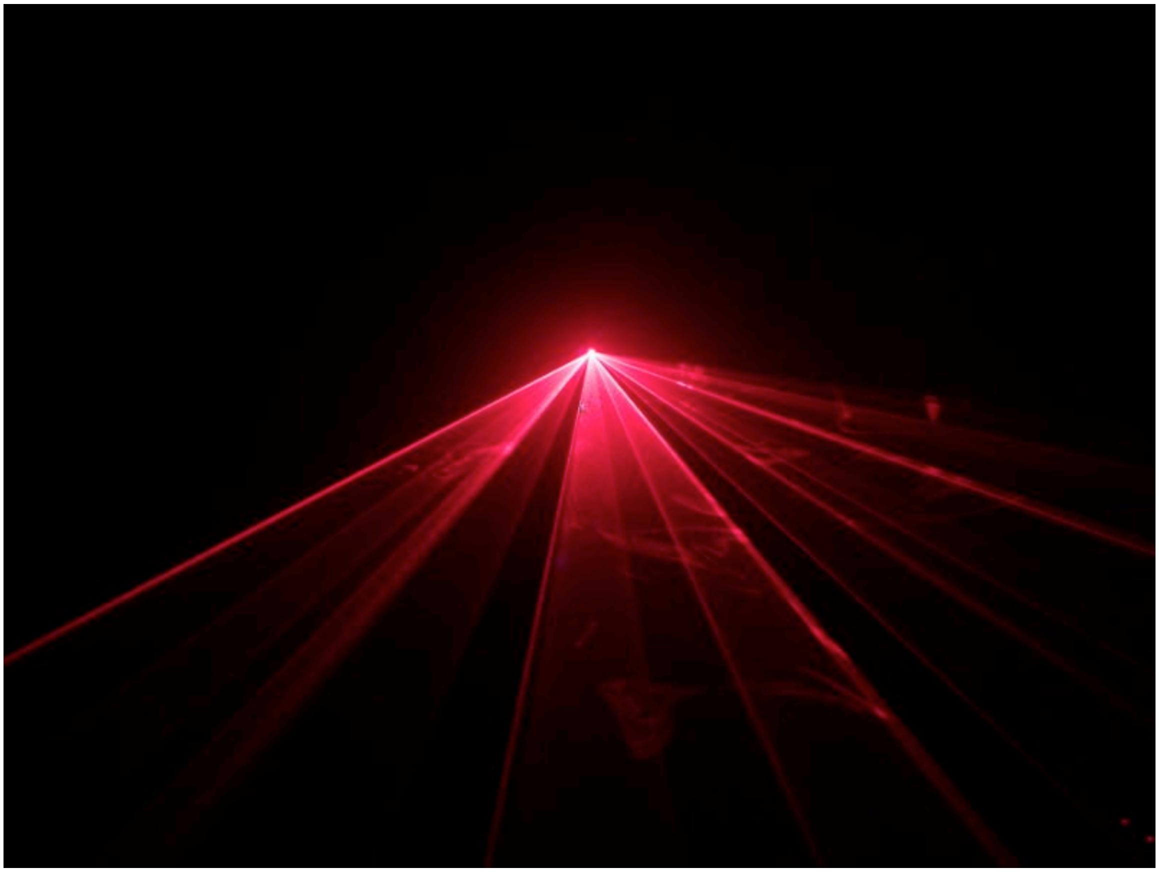

Figure 25 “Detail of As Far As We Know”, 2012

Following my fall semester research, I spent the remaining half of the year exploring modes of articulating space, time and movement with other forms of light. My research for the winter semester was concerned with how light informs not only space, but our perception of surfaces and objects. Working with projectors, I learned how to project images onto the surfaces of objects using projector mapping software. Within the software environment, virtual spatial maps of an object are created, mimicking the surfaces of the real environment. The software is then able to process images and video feeds, wrapping them around the surfaces of the real environment. Projector mapping effectively creates a dissociation between perception and reality; a spatial optical illusion.

Real Eyes: Realize: Real Lies, was the title for a series of explorations surrounding the use of projector mapping in sculptural applications. Using a variety of simple cuboidal geometric forms, I presented a number of mapping explorations that appeared to transform their surfaces through the perception of light projections. Although the

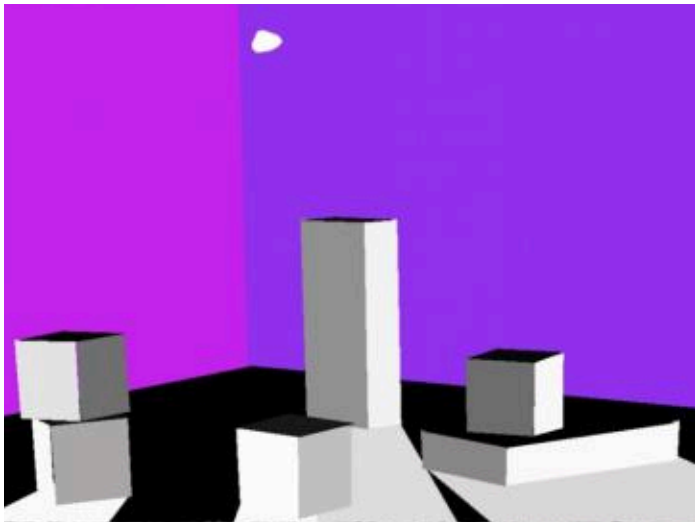

Figure 26 Real Eyes: Realize: Real Lies, 2013

cuboidal forms were actually just painted white, the projections made them appear to change colour and shape. In some instances the surfaces of the objects were animated. The work explored the dissociation between the reality of an environment, and the perceptual experience of that space, the tension between reality and the mentally constructed image. The work also explored the relationship between delineation and displacement; the intangible and tangible modes of spatial articulation. While the objects displaced the gallery space, the beams of light transmitting from the projector delineated the gallery space in the same way that a perspective drawing delineates a two-dimensional surface.

Concluding Graduate Exhibition

My final graduate work, “Delineate and Displace”, is a culmination of my graduate research. Working with both laser and projection technologies, the piece explores light relative to communication, space, time and movement.

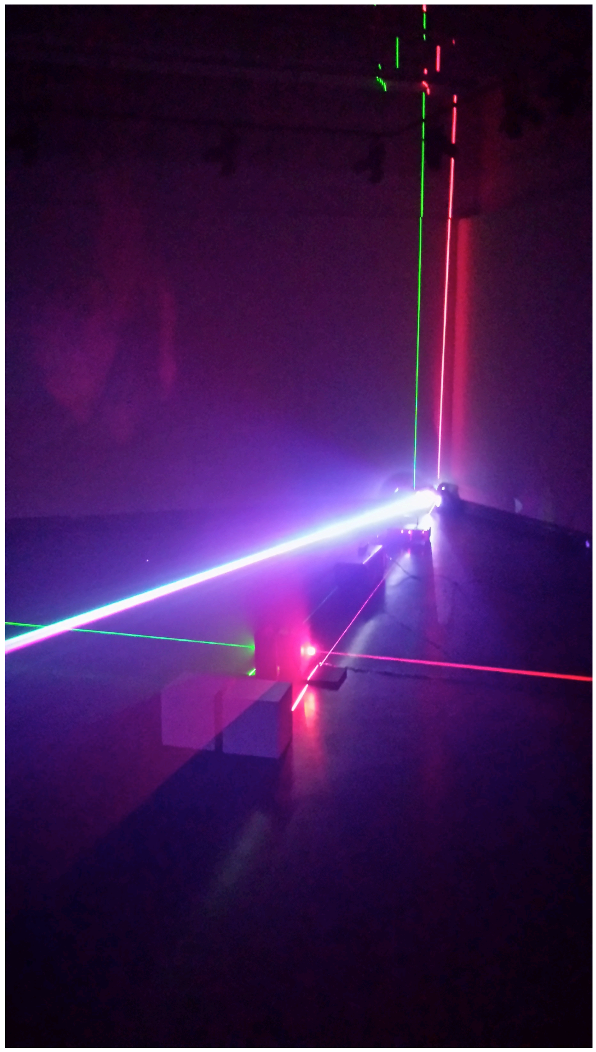

Figure 27 Delineate and Displace, 2013

Set up within the University of Calgary Department of Art’s Wunder Gallery is laser capable of producing all colours within the visible spectrum of light. Through a system of mirrors and simple mechanical devices, the laser's beam can be manipulated in the same way as with “As Far As We Know”, however it’s movement is imparted by an application that can read text messages from cell phones. The movement and projections created by the laser are captured via a closed circuit video system, and broadcast live within the graduate exhibition space of the Nickel Gallery. A scrolling marquee located under the live

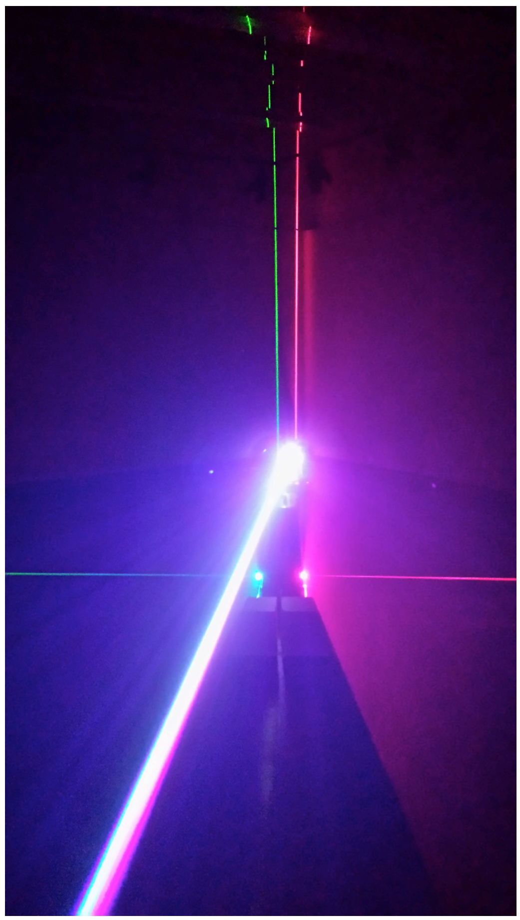

Figure 28 Delineate and Displace, 2013

broadcast projection prompts the audience to send text messages to the work through a dedicated phone line. As audience members send their text messages, the movements of the laser are controlled remotely. This movement is projected live on the gallery wall before them, providing a spatial visualization of speech, and a virtual representation of space.

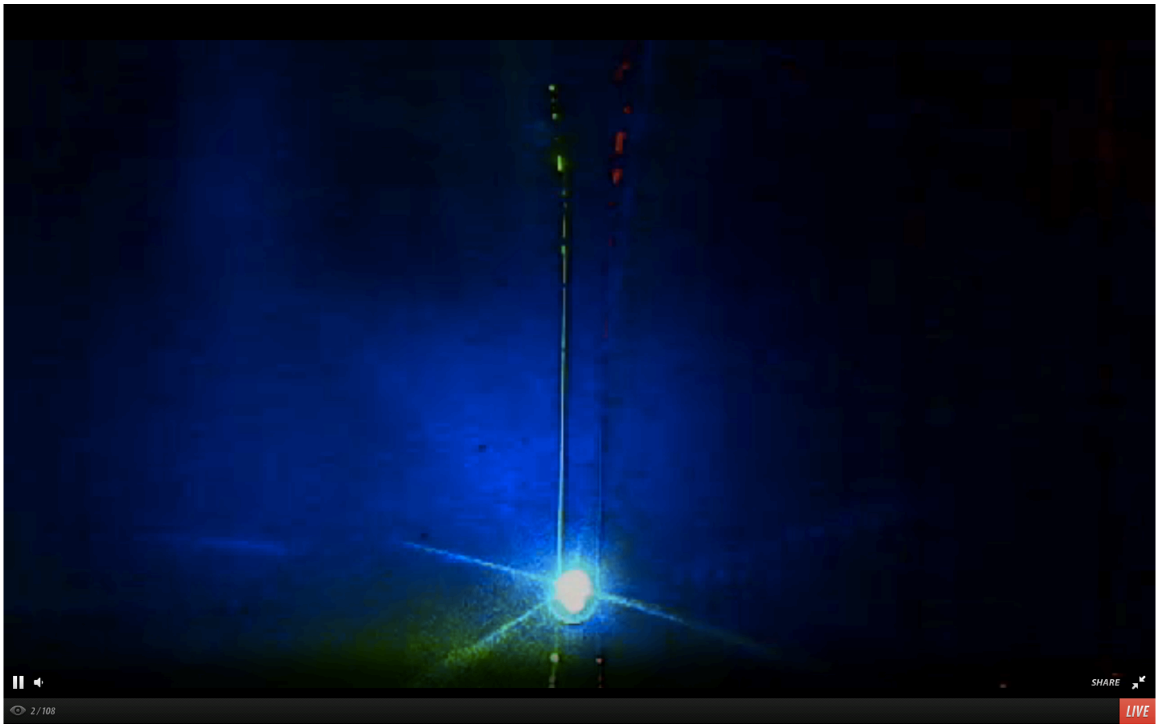

Figure 29 Delineate and Displace Projection in Nickel Gallery, 2013

This work is an expression of space in a number of ways. The most obvious is the use of a laser within the Wunder Gallery as an articulation of space, similar to the "Bird in Finite Space; Infinite Flight". The live video feed and dedicated phone line are articulations of technological space, the technological infrastructure required to allow for interaction and observation of the work. Through this technological space, the actual physical space between the Wonder and Nickel galleries are defined in the same manner that line defines the space between two points. There is a recursive component to the work that parallels the recursive and fractal nature of the world around us; the delineation of space. The laser beam is a delineation of three-dimensional space within the Wunder gallery, and the resulting patterns of movement on the gallery surfaces are articulations defining those two dimensional spaces. The subsequent projection of the laser installation on the wall of the Nickel Gallery is also a delineation of space, and articulation of two dimensional surface.

Through the use of telecommunication devices to inform laser movement within the Wonder Gallery, the work alludes to the notion of light as a conduit for information. This parallel relationship serves as a metaphor for the constant light-speed projection of information about our existence into the universe.

Bibliography

Adams, L. (2002). *Art across time*. Boston: McGraw-Hill.

Amedi, A., Merabat, L., Camprodon, J., Bermpohl, F., Fox, S., Ronen, I., Kim, D. S., & Pascual-Leone, A. (2008). Neural and behavioral correlates of drawing in an early blind painter: A case study. *Brain Research*. Retrieved from http://brain.huji.ac.il/publications/Amedi_et_al_blind-painter_BRES08.pdf

Asimov, I. (1982). *Exploring the earth and the cosmos: The growth and future of human knowledge*. New York: Crown.

Asplundh, R. (2010, July 1). Sun and Clouds [Photograph]. Retrieved from http://www.flickr.com/photos/51867225@N08/4769429374/in/photolist-8gszbW-5fANcz-aTfAi8-5ut13i-5KdvnQ-2bdta-6fuYxZ-Bhz5-7M98Tj-7vpDnd-fwfZ2z-efUUmQ-fwvfbY-fwg1Mn-dRirFX-aMo4g6-7MoETq-FRWXL-3fCPkM-gVD9z-9Hth4S-9Ekyqq-7bXDYD-49McQY-4xiijt-dfj5MD-97Fihi-gfNk-6UA9gq-7DWBs2-egifLq-egcv1D-5eLNM6-a6E97V-eTRNS-dpwNzx-a8hPjM-5rcbam-9DFRVT-ah3Ed-bWAVmh-tm6Ya-8TtDgL-aP5pqp-7Y5yxr-9D8r24-iL3Mg-dPjEg7-9FDSg-8Hgded-2DmUU

Ayliffe, W. (2013, February). The Human Eye and Vision | Gresham College [Video file]. Retrieved from http://www.gresham.ac.uk/lectures-and-events/the-human-eye-and-vision

Bahn, P. G. (2001). *The archaeology detectives: How we know what we know about the past*. Pleasantville, NY: Reader's Digest.

Bauval, R. (n.d.). *The Official Website of Robert Bauval - Home Page*. Retrieved February 2012, from http://www.robertbauval.co.uk

Bellis, M. (n.d.). *Famous Inventions - A - History of Famous Inventions*. Retrieved March 2012, from http://inventors.about.com/od/astartinventions/a/FamousInvention.htm

Brancusi, C. (1923). Bird in Space [Photograph]. Retrieved from http://classconnection.s3.amazonaws.com/377/flashcards/172377/png/screen_shot_2012-03-08_at_14142_pm1331235778620.png

Butterfield, J. (1993). *The art of light + space*. New York: Abbeville Press.

Castel, B., & Sismondo, S. (2003). *The Art of Science*. Peterborough: Broadview.

Chaisson, E., & McMillan, S. (2001). *Astronomy: A beginner's guide to the universe*. Upper Saddle River, N.J: Prentice Hall.

Clark, R. (1971). *Einstein: Life and times*. New York: World Pub. Co.

Clavilux 2000 | Jonas Friedemann Heuer - portfolio. (n.d.). Retrieved April 2012, from http://www.jonasheuer.de/index.php/clavilux-2000/

Clegg, B. (2008). *Light years: An exploration of mankind's enduring fascination with light*. London: Macmillan.

Coe, M. D., & Koontz, R. (2002). *Mexico: From the Olmecs to the Aztecs*. New York: Thames & Hudson.

Cohen, J. (2009, October 8). Stretching Time [Photograph]. Retrieved from http://www.flickr.com/photos/34580986@N03/3994908814/in/photolist-761Xdb-718bwT-5Zrv7Y-MEtri-hTTW2-8FguGG-71zh7g-mBL9W-7dqxz-8fFPJ4-7J5T7u-MyeNY-989W7G-4kQK48-4kULBf-4kULJ1-7oge1u-asipX6-f1FFN-dz7V7g-a4Qhv6-5cSYU-du3rF7-aCnmDF-3nqXV-8fEQyt-6e9gee-9wpfMA-aW23x6-MBMY-4bieE3-6aCxDs-5TS5to-6zhJ9b-3ZcoLQ-9RfiEN-6kAedr-FJkpS-39eYV7-8ZhtNZ-6GdycS-6FHfR3-c5abf-5NzwyZ-47rJ2e-5fNxpr-8uT8nN-bVfJDV-3iVdJs-vFcF4-ccBZdQ

Collins, J. (2007). *Sculpture today*. London: Phaidon Press.

Comandante, E. (2009, August 23). Monolito de la Piedra del Sol [Photograph].

Cytowic, R. E. (2002). *Synesthesia: A union of the senses*. Cambridge, Mass: MIT Press.

Dan Flavin - Early Work and Icons. (n.d.). Retrieved June 2012, from http://www.nga.gov/exhibitions/2004/flavin/early/early_p3.shtm

Devotional Christian (2011, May 4). Looking Fire in the Eye [Photograph]. Retrieved from http://devotionalchristian.com/looking-fire-in-the-eye/

Doesschate, G. (1962). *Oxford and the revival of optics in the thirteenth century*. Oxford: Pergamon Press.

Duchamp, M. (1913). Bicycle Wheel [Photograph]. Retrieved from http://imageobjecttext.com/2012/09/06/art-world-turned-upside-down/

Eadweard Muybridge Collections. (n.d.). Retrieved April 2012, from http://www.eadweardmuybridge.co.uk/

Eadweard Muybridge. (n.d.). Retrieved February 2012, from http://inventors.about.com/od/weirdmuseums/ig/Eadweard-Muybridge

Einstein, A., & Calaprice, A. (2005). *The new quotable Einstein*. Princeton, N.J: Princeton University Press.

The Electromagnetic Spectrum: A History - - Spectroscopy. (n.d.). Retrieved March 2012, from http://www.spectroscopyonline.com/spectroscopy/article/articleDetail.jsp?id=412203

Emerson, P. (2008, February 3). Gears [Photograph]. Retrieved from http://www.flickr.com/photos/8554856@N08/7871992906/in/photolist-cZC2eC-a7E8EJ-8rqmNG-pu2uJ-5nphx-6n2Nub-c3r5K-39B7Ug-9AnWJc-bqmxEt-7GDRue-6ARvgi-9QRNud-e6WJyZ-c2Gfaf-c2Gfm5-58nC1g-b6vNU-9mU1g1-5WgvSv-YJ4VQ-6iMWip-EX6Jw-dYVdKP-bu1EJa-8hDCW3-7g3xAd-a6KXx3-9B1tnm-cmPkkN-sdXmP-9KhTbj-bB13yf-9kVJyu-Cdgqh-8rrJMG-i2wwe-28wmFM-5rUy14-2atsUt-5sARbG-3Z7rhu-8ipHHw-dprgod-5unE25-byFHc-jxgjS-S5JE-8w1XUd-aFkRXv-35Q32r

Flavin, D. (1963). Diagonal of Personal Ecstacy [Photograph]. Retrieved from http://uploads2.wikipaintings.org/images/dan-flavin/diagonal-of-personal-ecstasy-the-diagonal-of-may-25-1963-to-constantin-brancusi-1963.jpg

Flavin, D. (1986). untitled (to Piet Mondrian through his preferred colors, red, yellow and blue) [Photograph]. Retrieved from http://www.davidzwirner.com/danflavin/

Garmire, E. (1970). Elsa Garmire's Dried Contact Cement Patterns [Photograph]. Retrieved from http://www.osa-opn.org/opn/media/Images/AfterImages/05may_10.jpg

Garwin, L., & Lincoln, T. (n.d.). *The first laser*. Retrieved March 2012, from http://www.press.uchicago.edu/Misc/Chicago/284158_townes.html

Goge, J. (2011, August 26). El tiempo vuela [Photograph]. Retrieved from http://www.flickr.com/photos/9021032@N02/6084211635/in/photolist-agDb9B-agFYGU-agDbne-6pTb2i-acBsho-acyApp-6ah3T3-8SrJ53-5W8Vv5-9uUeN1-7hwXNV-b46t6V-dLCjbn-3d1R9n-aC17qR-6tKsoH-6NbP5z-5pmge3-31B4mr-5wwivd-65JcNf-9mHkA-85mXP8-8tLGiP-8tZX3K-8A5FQB-7eeq5V-5VZhMu-a12u8d-FEiss-9ZYCwe-9ZYCLV-8SoHvM-acyAeK-acyCxX-9wqn1f-8SrJN5-8SoB1D-8SoGMi-8Sorjn-8SoEzk-8Srz9C-8SosdZ-8SouYT-8Sryju-8SoE3i-8SotbP-8SoBJg-6Po1kE-6Po1FN-6w4t2d

Greene, B. (1999). *The elegant universe: Superstrings, hidden dimensions, and the quest for the ultimate theory*. New York: W.W. Norton.

Grotzinger, J. P. (2007). *Understanding Earth*. New York: W.H. Freeman.

Halvey, S. (n.d.). *Einstein the Artist*. Retrieved March 2013, from http://larouchepac.com/node/20891

Hawking, S. (1998). *A brief history of time*. New York: Bantam Books.

Hester, J. (2011, July 11). Optical Illusion [Photograph]. Retrieved from http://www.flickr.com/photos/49503179907@N01/5927726415/in/photolist-a2P9xz-kYAJN-gcM3A-5MmCqM-bbE5eP-8nNp4r-aG4A3a-9Ru7zj-6aAC7H-aitXTN-qheba-5s2X7J-ba5WWZ-8h4PuF-8h84J9-qWRBf-9inxse-bUWUJj-9imyxV-9iBQE6-zc1Cj-3e9Bnu-mx6fS-4EVz6L-ciDh6-5z6NTU-a8cn2L-a89tAT-a89tuz-a8cn3G-5KM2yG-6WknS-CjwJm-6MYurk-5JBWrv-7VpsNz-S1Kdq-tYhu-aG5wRn-6F38BK-fbBR9p-3iqqjq-aaxeTN-6wZDKX-5nCUrg-7HGmXD-7Azgv9-7AvuXi-7AzgsA-4pwUze-5tdvnN

Heuer, J. F. (n.d.). *Clavilux 2000 | Jonas Friedemann Heuer - portfolio*. Retrieved April 2012, from http://www.jonasheuer.de/index.php/clavilux-2000/

Hope, E. O. (1921). Albert Einstein Violin [Photograph]. Retrieved from http://commons.wikimedia.org/wiki/File:Albert_Einstein_violin.jpg

Human Evolution Timeline Interactive | The Smithsonian Institution's Human Origins Program. (n.d.). Retrieved March 2012, from http://humanorigins.si.edu/evidence/human-evolution-timeline-interactive

Janson, H. W., Davies, P. J., & Janson, H. W. (2004). *Janson's history of art: The western tradition*. Upper Saddle River, N.J: Pearson Prentice Hall.

Japanese Device Uses Laser Plasma to Display 3D Images in the Air. (n.d.). Retrieved March 2012, from http://phys.org/news11251.html

Jung, C. G. (1963). *Memories, dreams, reflections*. New York: Pantheon Books.

Kemp, M. (2000). *The Oxford history of Western art*. Oxford: Oxford University Press.

Kingston Museum and Heritage Service, & Kingston University (n.d.). *Eadweard Muybridge Collections*. Retrieved March 2012, from http://www.eadweardmuybridge.co.uk

Knight, G. (2008, September 28). The Colours Of Music [Photograph]. Retrieved from http://www.flickr.com/photos/8176740@N05/2952170630/in/photolist-5uSDtC-5BorW9-9ZSqsF-9ZSqs4-8AAAvo-78AEL5-4HQ8At-9fBRm2-d15V3s-d15UkL-d15LPw-d15TFE-d15T6o-d15P7s-d15SBy-aNJGna-32YeYY-aqAFEW-dPWUAd-aqAG21-aqAFr3-aqAGpd-9ZVk3o-cZzXBC-dCkY6f-7q5bYP-dKh7fu-6jBKLh-6Sh3BD-8HGrdw-6pMzTj-gyWdS-7qK2MR-9ZSqrT-4wBoSx-9q5TQF-d15PJo-d15Qfw-7CJiY9-gzdYQ-boKbLY-5PD9Ks-6LjhEk-8YTi8n-7TYVRu-7TYWEd-7TVGZP-7TYVXA-7TYWf1-7TYWzj-5sohZS

Leonardo On-Line: Art, Science and Technology. (n.d.). Retrieved February 2012, from http://www.leonardo.info/

Liebermann, M. (2013, July 2). Four Elements - Earth, Water, Fire and Air [Photograph]. Retrieved from http://www.flickr.com/photos/26622758@N00/9414956021/in/photolist-fkY7pX-8hXB1s-8hUn8e-8xinAu-81mm9p-4ZtLbs-jNb6H-eMxGi-e4UuyR-9x5wwd-5bkdW5-f7nMoG-fa2ygr-fagMYN-a4bF9a-7FQZAM-zfzUM-81pwfL-egWpdt-6CX4A1-k8jMM-eXQJ2-eMAqt-7h1dd8-5Wv1kE-6LTU-bkmLtk-fagNpo-jFqoY-4ZAWxL-bndgsA-7zvWs-dfZYay-5J9RYc-bak32F-5Choha-5ChknM-5CnhGf-5Cno2Y-5CmTaY-5CnGXY-5CiFtg-5Cnm1b-5ChsHX-5Ciden-5Cishg-5Cn22s-5CmDR7-5CncQQ-5CixLT-5ChqdK

Light: Particle or Wave? - - Spectroscopy. (n.d.). Retrieved March 2012, from http://www.spectroscopyonline.com/spectroscopy/article/articleDetail.jsp?id=337288

Making Sense of Marcel Duchamp | text only. (n.d.). Retrieved February 2012, from http://www.understandingduchamp.com/text.html

Malina, F. J. (1974). *Kinetic art: theory and practice: Selections from the journal Leonardo*. New York: Dover Publications.

Mandelbrot, B. B. (1983). *The fractal geometry of nature*. New York: W.H. Freeman.

Matthews, L. J. (2009, October 14). Broken Vase [Photograph]. Retrieved from http://www.flickr.com/photos/mythoto/4152137341/in/photolist-7jUMLR-6ysWfD-8SCtLx-8SFxZG-8SCsMt-8SCt8a-9NiRRK-4z7Jza-7G4YUN-dzj9nU-aSKrE8-89hhGn-h2LV-eb2eiB-vqv44-PRNt4-LkZv1-9NgNCd-eb2ehF-eb7R3d-eb7R47-eb2egk-eb7R4C-eb7R3j-eb7R4m-eb2eh2-eb2eic-9Ne6sa-9NmzJh-7Fsqt4-hEZqK-49AEGd-5D5989-4BpEw9/

Miller, A. I. (2001). *Einstein, Picasso: Space, time, and beauty that causes havoc*. New York: Basic Books.

Moholy-Nagy, L. (1930). Moholy-Nagy’s Lichtrequisit einer Elektrischen Bühne [Photograph]. Retrieved from http://arthistory.about.com/od/from_exhibitions/ig/bauhaus_1919_1933/bauhaus_moma_09_45.htm

Monet, C. (1897). Stacks of Wheat (End of Summer) [Photograph]. Retrieved from http://commons.wikimedia.org/wiki/File:Wheatstacks_(End_of_Summer),_1890-91_(190_Kb);_Oil_on_canvas,_60_x_100_cm_(23_5-8_x_39_3-8_in),_The_Art_Institute_of_Chicago.jpg

MSR (2007, April 6). Apples [Photograph]. Retrieved from http://www.flickr.com/photos/93922058@N00/448820990/in/photolist-FEjQW-vMwVi-4pwE6Q-fPErp-z8z6J-9BEcEF-5kiozw-mzv4W-2JnGq-5Ya2P6-bp7A3-x6ZDn-ARaAo-D7PTG-6jkoD1-6j76d5-6j73XG-6j74Jb-4xaEfs-6j5iUJ-6o8q5g-mN49H-3o4FFs-4beqdT-opbkp-5HJ5c1-2hYsBf-53YmxB-4sbJ3S-5ET4v4-3m5WDK-X569S-8QCwYW-r3Em3-qqUyA-3iumm5-5uVQgU-EHf46-2WagjU-q1weZ-38oDHp-8a3U6T-495kcc-4zPMrQ-9CEXe-2LKabf-4dsaxS-n1MgL-5KdE45-2rVTG6-r3EoU

Muybridge, E. (1904). Sequence of a horse galloping by Eadweard Muybridge [Photograph]. Retrieved from http://commons.wikimedia.org/wiki/File:Muybridge_horse_gallop.jpg

NASA, ESA, & Hubble Heritage Team (2011, April 20). A rose made of galaxies [Photograph]. Retrieved from http://www.spacetelescope.org/images/heic1107a/

NASA (2011, August 24). Hurricane Irene [Photograph]. Retrieved from http://www.flickr.com/photos/28634332@N05/6082263563/in/photolist-agtc4a-agtb6r-agws2k-agz8ww-agynn7-dNBDxw-6RzyAy-8xC3dc-Rv4r-8vSydV-3bMiwD-c5eStQ-8vVL9d-evEF5G-8v2fmx-afXbUE-52EMn-ZvTVS-ZvTQJ-8xs7E7-8xp2q6-8dgF5t-agPnbW-8xsdYo-8xp9Yz-9NH11D-a6UEsn-8xPxcH-d9xPGQ-azGyiH-afMn4j-8wZtNT-9NAsCc-Fwc38-dAaGdf-4zwmX-5hBFo7-5hQr4g-5eQ3zp-54NbYS-9utSdV-xak6n-8x8Po8-8vsG7j-5m6gnm-5t8Bzh-asBpn-d34FpW-ah6bnJ-5m1d9x-ZvdAJ

NASA (2013, January 30). Massive Solar Flare, Skylab Telescope [Photograph]. Retrieved from http://www.flickr.com/photos/28634332@N05/8429036469/in/photolist-dQR1SZ-8zypei-bjB81x-eBEmjX-97nyAt-eBHjih-twCdY-4CG5fv-9drLdP-5mpuD-2sXqXJ-8yHQsm-dUnbM3-9i3moi-3oCdL-9dRcDG-9o9TJE-anjW39-bsgatG-bv8P5M-bv8Liv-aAUsP9-56J13C-47MY8A-6MUur3-3VvwF-crxydh-8Z13u-2YNBVy-d6TDWY-9QR7Ln-8t9ApU-8xbgde-bhWPJn-9RfyVZ-7esnn5-5iciuV-Dv7Yr-Dv7Zn-bBf64c-aquNCC-bozDeN-bozD8Q-bBuytk-bBuyxr-bozDhG-bhsvwk-36Cw7y-absVw6-dTG44v-dYwKNe

NASA (2011, March 7). Space Station Over Earth (NASA, International Space Station, 03/07/11) [Photograph]. Retrieved from http://www.flickr.com/photos/28634332@N05/5512309055/in/photolist-9p72ri-4aCy1f-733uUT-fu23HQ-bEhv45-bTceAv-bEhuUb-bTceAx-ePyHtu-fbcmQ3-4BkXzN-72hXSg-6bEE4E-8d2ALu-9p6XPX-abRBS-cCTs3j-5ydR3T-bXY2RA-9ptt7w-ckswS3-8mCRsr-9bcpbv-33pGA-8fxkZy-6gp9PP-UAZkA-7iMfC8-8v1MNj-2JU8Kf-bvA1Ji-9y9kH7-5YN9Tj-6XaNgL-4ViBvo-8UAsn2-8zYbHD-5bePat-9nG4ub-9YFU3R-T9qsP-9EWMqS-2kHbB5-a2MiUJ-6CG9uj-6W9vnt-4wq3od-cksrgm-VXpBf-9y17bV-fxJ2ix

New world encyclopedia (n.d.). *Heraclitus - New World Encyclopedia*. Retrieved February 2012, from http://www.newworldencyclopedia.org/entry/Heraclitus

The Nobel Prize in Physics 1921. (n.d.). Retrieved February 2012, from http://www.nobelprize.org/nobel_prizes/physics/laureates/1921

The Official Website of Robert Bauval - Home Page. (n.d.). Retrieved April 2012, from http://www.robertbauval.co.uk/index.html

Perez, N. (2007, December). Lascaux [Photograph]. Retrieved from http://www.newworldencyclopedia.org/entry/File:Lascaux_03.jpg

Pinna, B. (2008). *Art and perception: Towards a visual science of art*. Leiden: VSP.

Plato, & McDowell, J. H. (1973). *Theaetetus*. Oxford: Clarendon Press.

Poort, E. (2007, March 18). Eye in Sky [Photograph]. Retrieved from http://www.flickr.com/photos/19707634@N00/425542588/in/photolist-DB1Zb-avRY-KktKb-M4aQK-aevR6f-8V1DUM-5nmjCF-8WxS6V-928AJw-5AiPvc-8Y3vmU-4rRyHh-4Voz8-xhVAv-77SmH7-wEL7w-4X5eQq-7TC1WE-34xh21-8Mn3cq-aZsvca-s5DdE-9aWGJf-aWNs1e-5dwqwc-bHQiJD-69RGxU-ep6cN5-ep69gy-ep69W7-ep6bUE-ep68W5-ep6cVb-ep68Dh-ep6aGJ-ep6bnq-ep6bLh-ep679j-ep6dW3-ep6eEq-ep69tJ-2hWLfj-ajwHU-4LjYmh-c7Uh8U-c7UgWA

Popper, F., & Bann, S. (1968). *Origins and development of kinetic art ... Translated ... by Stephen Bann. [With illustrations.]*. Pp. 272. Studio Vista: London; Epe printed.

Power From The Sun :: Chapter 2. (n.d.). Retrieved February 2012, from http://www.powerfromthesun.net/Book/chapter02/chapter02.html

Pre-Socratic philosophy - New World Encyclopedia. (n.d.). Retrieved March 2012, from http://www.newworldencyclopedia.org/entry/Pre-Socratic_philosophy

Roberts, W. (2008). *Seurat - Einstein - Monet - Maxwell. Parallels between art and science*. Retrieved April 2012, from http://www.principlesofnature.net/connections_between_art_and_science/seurat-einstein_monet-maxwell_parallel_views_of_light.htm

Rostad, B. (2005, March 26). Kufu's Great Pyramid [Photograph]. Retrieved from http://www.flickr.com/photos/brostad/232528949/sizes/m/in/photolist-mxLKP-63EoY8-4GvJhV-8cdpAt-6T45QG-6T46uA-bDE4b7-bmd51N-bz8hFa-bmeoZw-bz9mnT-bmdwMW-bmenFb-89UtSZ-9uTgs4-

bz8ycX-75BW8q-55khpo-55g5Z2-bffHj4-54VT1g-39LYrP-64FT1M-65LeE2-djKpkb-djKitT-djKpHn-djKp8i-djKpVo-bz7V7D-63EiX8-7BH3ds-8kEstz-7BH7xQ-7wxFfA-4iwVZn-4iAUSs-4iwTK2-4iAU9d-4iASvY-4iASwj-4iwQkr-4iwPRV-4iATKJ-4iATtf-4iATgL-4iASVs-4iATX1-4iwUFP-4iB1d9-4iAYoS/

Sandberg, A. (2011, November 11). Macaque brain connectivity [Graphic]. Retrieved from http://www.flickr.com/photos/87547772@N00/6335024542/in/photolist-aDNE65-aKxrzi-DWwGq-9ibgW1-7vzuoH-9LgdFF-jNCRW-cXPbod-bxRASr-78uZJy-8Him9f-cTWiA-yRRDS-cKsCHw-6q6QG2-4oRM7D-cfRiAb-cXPbT9-arquPh-4oRUnZ-5JmSsP-5Jr9Gq-5JrhfU-5JrbaN-5JmWcZ-fwecZ-8xapWL-bEqZCo-bEr16j-bTkJ78-bEr1k7-bTkJjz-bTkJdv-bEqZ1b-bEr1wb-bTkJLM-bEqZdf-bTkHsK-bEqZr5-bTkHTF-dKCa5-35tcWX-5bnBnE-dnf1dp-7ecmnL-2xdo6Y-6QGGP3-dJ2JdK-fmuKD5-7e8tvD-7e8ttB

Sarcone, G. A., & Waeber, M. -J. (2011). *Amazing visual illusions*. London: Arcturus.

Sayen, J. (1985). *Einstein in America: The scientist's conscience in the age of Hitler and Hiroshima*. New York: Crown.

Seurat - Einstein - Monet - Maxwell. Parallels between art and science. (n.d.). Retrieved February 2012, from http://www.principlesofnature.net/connections_between_art_and_science/seurat-einstein_monet-maxwell_parallel_views_of_light.htm

Seurat - Einstein - Monet - Maxwell. Parallels between art and science. (n.d.). Retrieved March 2012, from http://www.principlesofnature.net/connections_between_art_and_science/seurat-einstein_monet-maxwell_parallel_views_of_light.htm

Seurat, G. P. (1884). eurat, Sunday afternoon on the Island of La Grande Jatte [Painting]. Retrieved from http://upload.wikimedia.org/wikipedia/commons/4/4d/Georges_Seurat_-_Un_dimanche_après-midi_à_l%27Île_de_la_Grande_Jatte.jpg

Shark, A. (2006, August 22). Thine Eye [Photograph]. Retrieved from http://www.flickr.com/photos/58064156@N00/222037336/in/photolist-kBZXW-6iRUKc-Nymow-8XFtSu-6fhAy5-v8dVD-5jmiW3-dyBgRo-4fihZm-5rR9uR-9VNzrS-6jqsDj-8X8EBP-6HGQw8-91Hean-9iWwGY-eFQoYk-8pcQRt-bN6KYg-9hvccM-8fS1x-nX4eg-3gbCze-aVb3Ek-5QmrwV-8Sgd4C-6GgNTe-bnaKvt-8x4GDh-9vBguE-

N3zaU-83EkMQ-5CWUaM-b7UtkK-8kbbPt-7QXqRE-a1VJoh-mfkPu-mfkMZ-mfkLA-8i1b1n-5gK4j6-dhf3FQ-51RBwg-axLdm7-dQYjaN-f9Z1AL-6WaQLR-5TijU9-e3jxoJ-AY6nn

Sparrow, G., & Sobel, D. (2007). *Cosmos*. London: Quercus.

Speed of Light | United Visual Artists. (n.d.). Retrieved March 2012, from http://www.uva.co.uk/work/speed-of-light

Sudarshan, V. (2008, August 2). Handful of Treasure [Photograph]. Retrieved from http://www.flickr.com/photos/chitrasudar/2740220523/in/photolist-5b9m6r-7x6THi-9wFih3-9wCjmr-a9Lwej-3hqMpP-5daet6-8eS2cr-76w9U4-4sQHEA-9WrxcG-aFRMVM-7Sz6Nn-61Xmpu-61T9dD-61T8F4-61XkhW-61T9Mr-61XkV7-a2jfwf-aF7Jvv-adKEjs-aFbyBG-dUXqSs-dURQQt-5cxEwY-BG2uQ-mUFYT-aiVLam-8DjXBv-e6HoKg-6zstFQ-h1mz5-544wCu-3JNH2L-5E88mU-8ztqna-4mNSv2-abHsEW-dQfBsq-t3eLr-3quAjq-4PsGWL-bZ43n-gBmvP-Kbqy2-51bcSL-73RxDH-Lp33N-3kGsgL-8YHFzX/lightbox/

Suzuki, S. (1969). *Nurtured by love: A new approach to education*. New York: Exposition Press.

TED: Ideas Worth Spreading (2009, May). Mae Jemison: Teach arts and sciences together | Video on TED.com [Video file]. Retrieved from http://www.ted.com/talks/mae_jemison_on_teaching_arts_and_sciences_together.html

Tessmacher (2011, June 15). Rods [Photograph]. Retrieved from http://www.flickr.com/photos/12257795@N03/5837561087/in/photolist-9TR2wX-9zTsuh-3TYGPS-7dq11Y-64p7gj-gxAYN-anbedL-yrnzc-9mrp5-9mrox-9mrog-9mrpo-czK28m-mU26P-8c161T-9GhXBn-6W4s9Q-dNmG4t-9HdbDJ-5dopRY-6fAtNz-6dbbpq-at7uYC-6Eba6r-66HkQN-5Pq6E1-5Pq6Cm-61X9QA-61X9Q1-61X9PC-3bPw5n-5PkPhg-5PkPgp-FzWMM-4pivNB-a4UirD-6XJAyL-5vYu9D-29LcQ1-avzVZK-86MPqm-ehWYt7-5jjGg4-3ikfYP-xbNbk-e81eR3-4VBGQr-5bQmwC-bKWQwg-af2B9s-3Hi4Nd

Turrell, J. (2010). Dhatu 2010 [Photograph]. Retrieved from http://magazine.saatchionline.com/wp-content/uploads/2010/11/JAMES-TURRELL-2010_Dhatu-JPEG.jpg

Types of Synesthesia | The Many Faces of Synesthetes. (n.d.). Retrieved April 2012, from http://www.synesthesiatest.org/types-of-synesthesia

Tyson, N. D. (n.d.). *The Most Astounding Fact (Neil DeGrasse Tyson) | NASA Lunar Science Institute*. Retrieved May 2012, from http://lunarscience.nasa.gov/articles/the-most-astounding-fact-neil-degrasse-tyson/

UVA (2010). UVA Speed of Light [Photograph]. Retrieved from http://www.uva.co.uk/wp-content/gallery/speed-of-light/uva_sol_9328.jpg

Web Gallery of Art (2011, June 11). Leonardo da Vinci - Self Portrain [Photograph of Drawing]. Retrieved from http://www.wga.hu/frames-e.html?/html/l/leonardo/08heads/12selfpo.html

Weibel, P., & Jansen, G. (n.d.). *Light Art from Artificial Light | Curatorial concept*. Retrieved February 2012, from http://hosting.zkm.de/lightart/

Weibel, P., Jansen, G., & Museum für Neue Kunst (Karlsruhe, Germany) (2006). *Light art from artificial light: Light as a medium in 20th and 21st century art = Lichtkunst aus Kunstlicht : Licht als Medium der Kunst im 20. und 21. Jahrhundert*. Ostfildern, Deutschland: Hatje Cantz.

Wertheimer, M., & In Asch, S. E. (1945). *Productive thinking*. New York: Harper & brothers.

Wiehager, R. (2009). *Minimalism and after: Tradition und tendenzen minimalistischer Kunst von 1950 bis heute : Neuerwerbungen für die Sammlung 2000 bis 2010 = tradition and tendencies of minimalism from 1950 to the present : new acquisitions for the collection 2000 to 2010*. Ostfildern: Hatje Cantz.

Wikipaintings.org (1912). Nude Descending a Staircase, No.2 - Marcel Duchamp, 1912 [Photograph]. Retrieved from http://www.wikipaintings.org/en/search/Duchamp%20nude%20descending%20staircase/1#supersized-search-234899

Winer, G. A., Cottrell, J. E., Gregg, V., Fournier, J. S., & Bica, L. A. (2002). Fundamentally misunderstanding visual perception: Adults' belief in visual emissions. *American Psychologist*, (57), 417-424.

Wiscombe, G. (2007, July 30). Stonehenge [Photograph]. Retrieved from http://www.flickr.com/photos/garethwiscombe/1071477228/in/photostream/