California Institute of the Arts

Imperceptibility in Nature

Artistic Approaches to Examining Systems Beyond our Perception

by

James Meason Wiley

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Supervisory Committee

Dr. Ajay Kapur

Mentor

Dr. Owen Vallis

Committee Member

Dr. Jordan Hochenbaum

Committee Member

“It is entirely possible that behind the perception of our senses, worlds are hidden, which we are unaware.” - *Albert Einstein*

Abstract

The following thesis focuses on various artistic approaches to exploring and augmenting the hidden complexity of structures within our natural environment. Within the context of this thesis, the investigation into natural phenomena is intentionally limited to examining our sonic environment, mechanical and longitudinal waves, and the underlying physical properties of sound and vibration. This limitation was set in order to create a sense of consistency regarding the presented work. Additionally, it serves as a means to help create a coherent framework for work itself. As an artist, one of my primary concerns is to allow within the work itself, a space for the exploration of a multitude of perspectives regarding a single idea. Many artists whose work I consider highly influential have utilized a similar approach. The frequentative approach to art is a very important aspect of my work, one that I will attempt to provide an appropriate context for in the following chapter. The following thesis is arranged to reflect three of the primary works I was responsible for creating while pursuing my Master of Fine Arts in Music Technology at California Institute of the Arts. In the following chapter, I will provide an overview of the projects associated with this thesis, and discuss their contextual relevance. Chapter 2 will provide both a contemporary and historical artistic context for the conceptual and aesthetic aspects of my work. Chapter 3, "Visible Sound", will deal with the project *NODE*, which is an interactive sonic/visual installation that explores the complex harmonic relationships of sound through the use of modal phenomena. Chapter 4, "Mechanics of Sound", will discuss the project *Cycle*, a large-scale kinetic sculpture that attempts to visually interpret and represent the physical 3-dimensional characteristics of a mechanical waveform. Chapter 5, "Tangible Sound", will examine the work *Phase/Spectrum (series)*, an ongoing set of topographical sculptures depicting the complex harmonic relationships of sound by creating an augmented physical sound/data imprint of various sonic phenomena. The final chapter of this thesis will include a general summation of my thesis, including a short discussion regarding future work. These projects represent the focal point of my artistic exploration into the examination of natural systems beyond our perception.

Acknowledgments

I would like to thank the following people for their contributions to the projects associated with this thesis: First and foremost, Amber Lepley (MFA – Technical Direction, CalArts), whose contribution in terms of time, skill, and energy, as well as her friendship throughout this process have been an irreplaceable gift. Amber was crucial to the success of these projects, and her passion and belief in this work kept me going when sleep was not an option. Without her support and hard work, this thesis, and the projects discussed on these pages would not exist. Michael Darling, Paul DiPietro, Oscar Arvelo, Zach Golden, Nicole Busson, and the entire Technical Direction department at CalArts for offering up their workspace to me for an entire year, and, for their patience, support, and individual contributions to these projects. I am forever grateful. Rose Malone, for her amazing lighting design of Cycle during the Digital Arts Expo. Eric Heep for his help problem-solving lines of code with me until 4 a.m. My mentor and dear friend, Ajay Kapur, Colin Honigman, J.P. Yepez, Spencer Salazar, Jordan Hochenbaum, Owen Vallis, Jim Murphy, Carl Burgin, Cordey Lopez, Rodrigo Sena, Shaurjya Banerjee, Daniel Reyes, Nathan Shaw, Davy Sumner, Martín Vélez, Sarah Reid, Dexter Shepherd, Wolfgang Foulkes, Mint Park, Zach Crumrine, Bruce Lott, Ness Morris, Jackson Duhon, Harmony Jiroudek, Jasmin Blasco, Joe Cantrell, and the rest of the MTIID department for their ideas, support and friendship. Thank you to CalArts for changing my life. Geoffrey Shulman and the faculty at Austin Community College (Music Business, Performance, and Technology), April Joy Gerloff, John-Michael Reed, Sonya Gonzalez, Derrick Ostrenko and the faculty and staff at LSU (CCT). Scott Groller and Ashwin Vaswani for all of their amazing photo documentation. Special thanks to Trimpin, Perry Cook, Curtis Bahn, Sarah Roberts, Neelamjit Dhillon, and Clay Chaplin for their friendship, support, inspiration, and words of wisdom. Thank you to the Herb Alpert Foundation for the academic scholarship. Thanks to all of my family & friends for helping me get through this chapter in my life. I love you.

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Chapter 1

Introduction

As an artist, I am fascinated by order and structure. The schematic of a beautiful circuit, to me, is as appealing as the design of the enclosure that houses it, or the utilitarian function of the circuit itself. Like the roots or veins of a biological organism, or the complex system of roads, buildings, and parks of a large city viewed from above - the inner-workings of a mathematical model in physics – the underlying organization of these structures are as interesting to me in terms of aesthetics and design as their representational facades. Additionally, the similarities between natural and man-made structures, invokes a sense of connectivity between the two that is often overlooked in our society. [1]

1.1 Biomimetics

The field of *Biomimesis,* which is *the study of the structure and function of biological systems as models for the design and engineering of materials and machines,* takes a very literal approach to these relationships, creating a mathematically symbiotic relationship between the structures of nature and the structures of objects that are man-made.[2] In terms of art, this same relationship is both conceptually and aesthetically linked to numerous works that focus on natural structures, both visible and invisible. Art that focuses on natural beauty, or the underlying structural elements of a natural or man-made system has been explored for many years, and across many artistic disciplines.[3] From the small-scale works of *Microphotography* [4]*,* to the massive works of the *Earth*

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1 http://www.huffingtonpost.com/carmen-zella/creating-connections-withland-art_b_4833677.html

2 What is Biomimesis? | Biomimetic Summit Barcelona 2016. (n.d.). Retrieved from http:/www.biomimeticsummit.com/ about-us/what-is-biomimesis/

3 Creating Connections With Nature Via Art. (n.d.). Retrieved April 8, 2016, from http://www.huffingtonpost.com/carmen-zella/creating-connections-withland-art_b_4833677.html

and Land Art movement of the 1960's [5], artists have consistently searched for meaningful ways of exploring the natural world, producing works with materials found directly from nature and often contextually or even physically linked to their natural environment. More recently, computer-based digital artists, benefitting from the advent of mobile computing, digital fabrication, and cost-effective technologies such as sensors and microprocessors have explored various processes of modeling and re-interpreting various components of nature, both in terms of what can be seen, and what is hidden.

Figure 1: Biomimetics in Art

1.2 Nature + Structure

Even in the field of *Generative Art,* where artists utilize advanced methods of computational processing and creative coding to develop autonomous systems, there is a often a direct

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[4] Micrographia: uncovering nature's hidden beauty. (n.d.). Retrieved April 8, 2016, from http://www.sciencefocus.com/gallery/micrographia-uncovering-natures-hidden-beauty

[5] Earth Art Movement, Artists and Major Works. (n.d.). Retrieved April 2, 2016, from http://www.theartstory.org/movement-earth-art.htm

correlation between the algorithm and it's natural cohort.[6] This symbiosis can be seen in the common use of flocking algorithms that mimic the flight of birds, fractal algorithms that reflect the mathematical intricacies of snowflakes, even advanced splining algorithms that mimic the physics of spider webs. With the advancement of digital fabrication techniques, including various CNC (Computer Numerical Control) devices, laser cutting, water jetting, and 3D printing, it is now possible to model complex structures found in nature via software and then re-create them in the physical world. These various approaches to recreating the complexity of natural structures show an implicit desire amongst artists to find connections between what exists in nature, and what is man-made. When describing the work of renowned biologist Ernst Haeckel and his text "Kunstformen de Natur" (1898), art critic Marco Mancuso stated *"it is undeniable that nature is able not only to create spontaneously real 'art forms', but also to produce a direct correspondence between a certain generative aesthetics, starting from a fundamental unit/nucleus to come to a complex entity, and a consequent adaptive and evolutionary practice."*[7]

1.2.1 Nature's Direct + Indirect Influence on Art

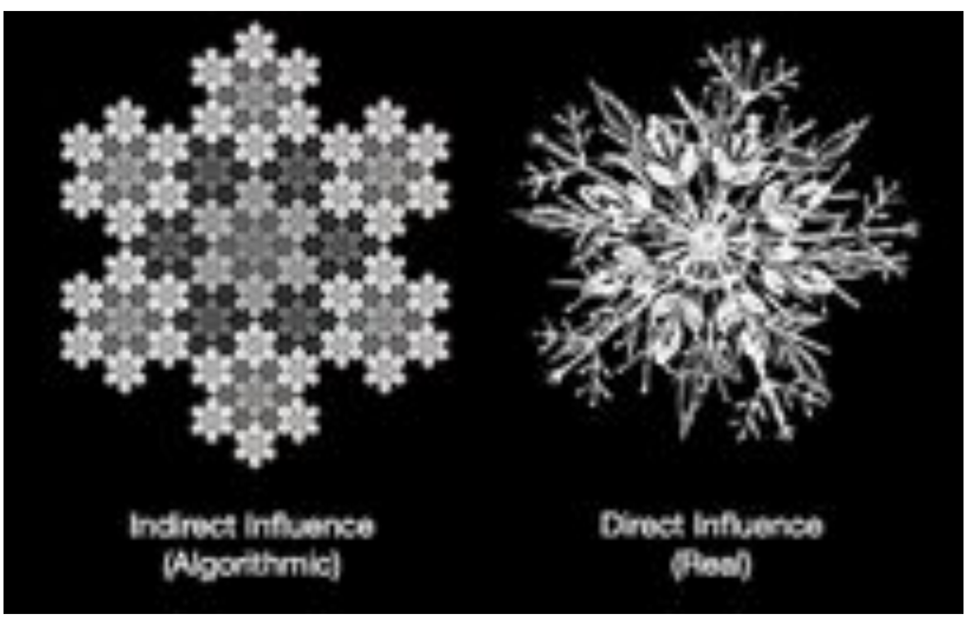

Figure 2: Indirect vs. Direct Influence

[6] http://www.generativeart.com/ga2013xWEB/proceedings1/22.pdf

[7] http://www.digicult.it/digimag/issue-041/generative-nature/

In these instances, the relationships between man-made objects and natural structures are unequivocally linked, either through direct or indirect influence. In terms of representing nature in art, there are two common approaches: *the simulation of natural phenomena through indirect means,* and the more literal approach of *presenting natural phenomena as it exists in nature.* This symbiosis with man-made and natural systems is the central theme to my work, and can be further broken down into three general themes: *Structure* (as described above), *Connectivity, and Movement.* These themes help to create a basis of approach while presenting the work laid out in this thesis, and are highlighted in more detail in the following section.

1.3 Natural Themes

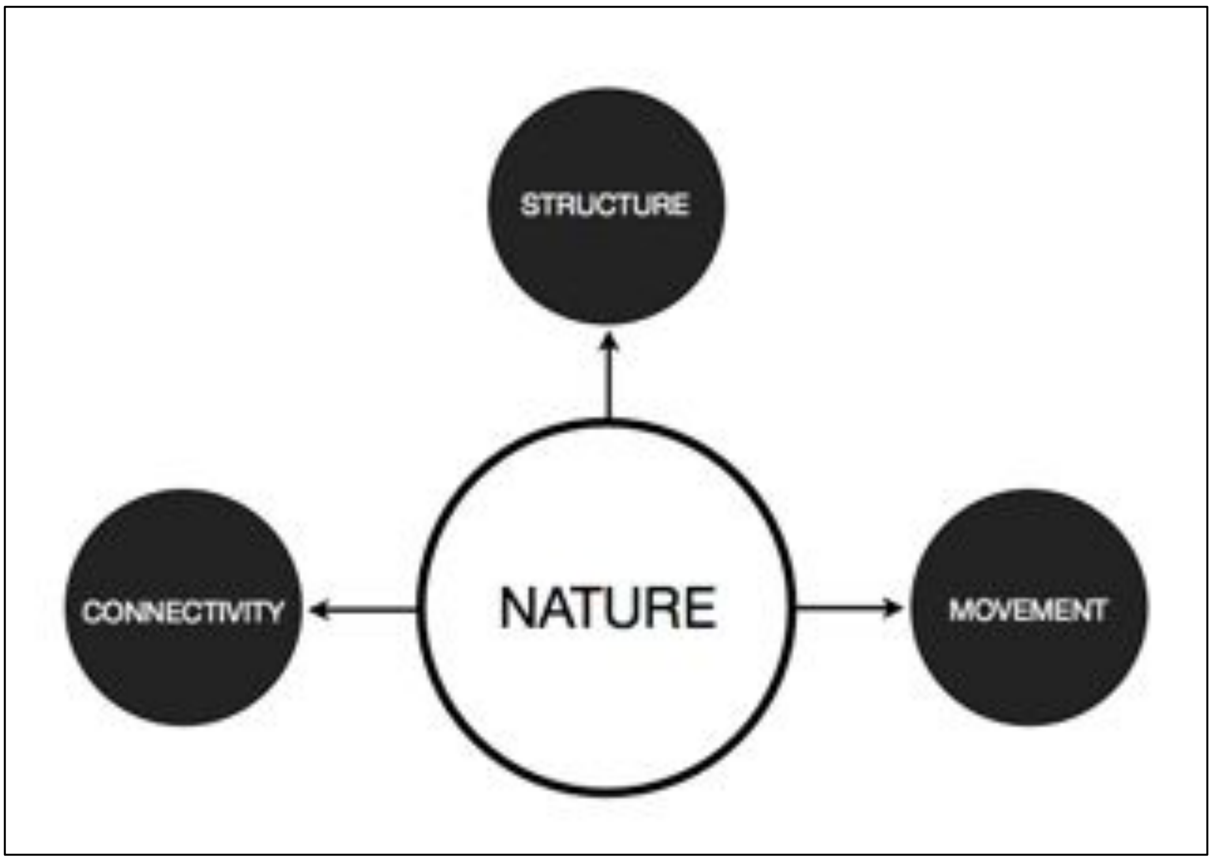

Figure 3: Structure, Connectivity, and Movement

1.3.1 Connectivity

The concept of *connectivity*, with regards to natural phenomena and art, is about finding ways to invoke a sense of connection between people and their natural surroundings. With our growing reliance on technology, as well as the increase in urban development, humans in the 21st century are slowly losing our sense of connection with nature. Just as technology has increased interconnectivity between people across the world, our reliance on technology, as well as our consistent trend towards centralized urbanization has created a rift with regards to our relationship with nature.[8] In many ways technology itself has become a replacement for nature; our connection to nature, more abstract and ambiguous. (Honigman 2013) Through my work, I hope to help renew a healthy sense of connectivity with the natural world that is both inherent and fundamental – one that serves as a reminder that humans and nature are forever interlinked. As renowned biologist E.O. Wilson once stated, *"Nature holds the key to our aesthetic, intellectual, cognitive, and even spiritual satisfaction"*.[9] In terms of human nature, it is only an illusion that we are separate from our natural surroundings.

1.3.2 Movement

The third general theme of my work and its relevance to nature and natural phenomena revolves around the concept of movement. In terms of this thesis, *movement* specifically relates to the fluid, dynamic motion of various forms of mechanical waves, as they exist in nature. Examining the physical, helical motion of sound as it travels through a medium brings to mind a number of similar perceivable structures that exist all around us. *Helices* are found throughout nature: built in to the physical structure of a seashell, or built up sonically through the harmonic series. (Weisstein 2016) They can be seen in the cyclical structure of the Milky Way galaxy as well as the microscopic strand of DNA.[10] A helix is essentially a curve in three-dimensional space, linking sine and cosine through equidistant tangents. The *spiraling* nature of a helix is much like a coiled spring, or the handrails of a spiral staircase. By focusing on this natural movement of sound, I hope to invoke these similarities from the viewer's perspective.

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[8] http://www.livescience.com/5389-humans-losing-touch-nature.html

[9] E.O. Wilson Biography -- Academy of Achievement. (February 26, 2010). Retrieved April 2nd, 2016, from http://www.achievement.org/autodoc/page/wil2bio-1

[10] http://io9.gizmodo.com/5985588/15-uncanny-examples-of-the-golden-ratio-in-nature

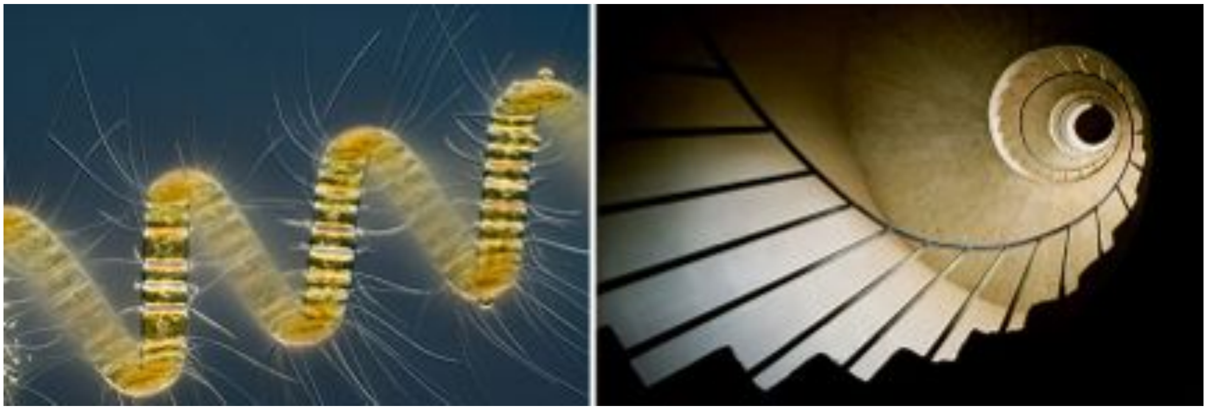

Figure 4: Helices – Microorganism and Spiral Staircase

1.4 Visualizing Sound

The work presented in this thesis centers around the concept of visualizing sound waves, as they exist in nature. Sound waves are essentially mechanical waves, created by a vibrating object that sets particles within a given medium into motion. This vibrating motion propels energy through the medium in the form of *longitudinal waves*. As a longitudinal wave propagates through a medium, the motion of the individual particles of the medium moves parallel to the direction that the sound is traveling. The sound wave ebbs and flows through the medium much like a coiled spring. The result of longitudinal vibrations is the creation of compressions and rarefactions within the medium.

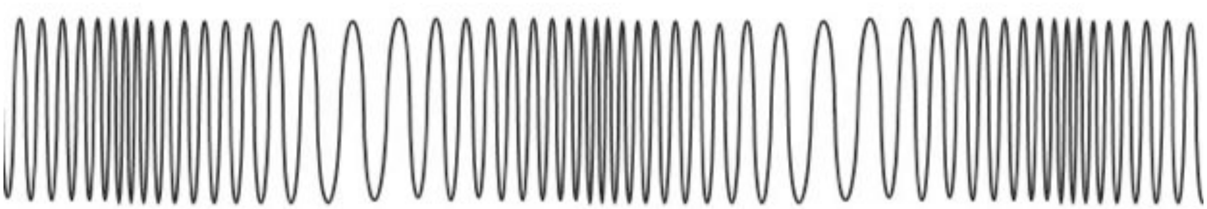

Figure 5: Sound Wave Propagation

Sound is not the only form of a longitudinal wave in nature. Primary waves, or *P waves* created from a seismic event are also longitudinal waves, as are tsunami waves. [11] Sound is, of course,

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[11] http://hyperphysics.phy-astr.gsu.edu/hbase/sound/tralon.html

invisible to the naked eye, but can be made visible by creating large vibrations in a physical medium such as water. However, we typically visualize sound waves by some means of analysis, using technology to sample and extract information from the wave in order to reconstruct it, either in terms of time or frequency. In order to generate a series of work meant to focus on viewing sound and vibration, I will show effective ways of utilizing a combination of these approaches to documenting and visually representing sound.

1.5 Thesis Overview + Outline

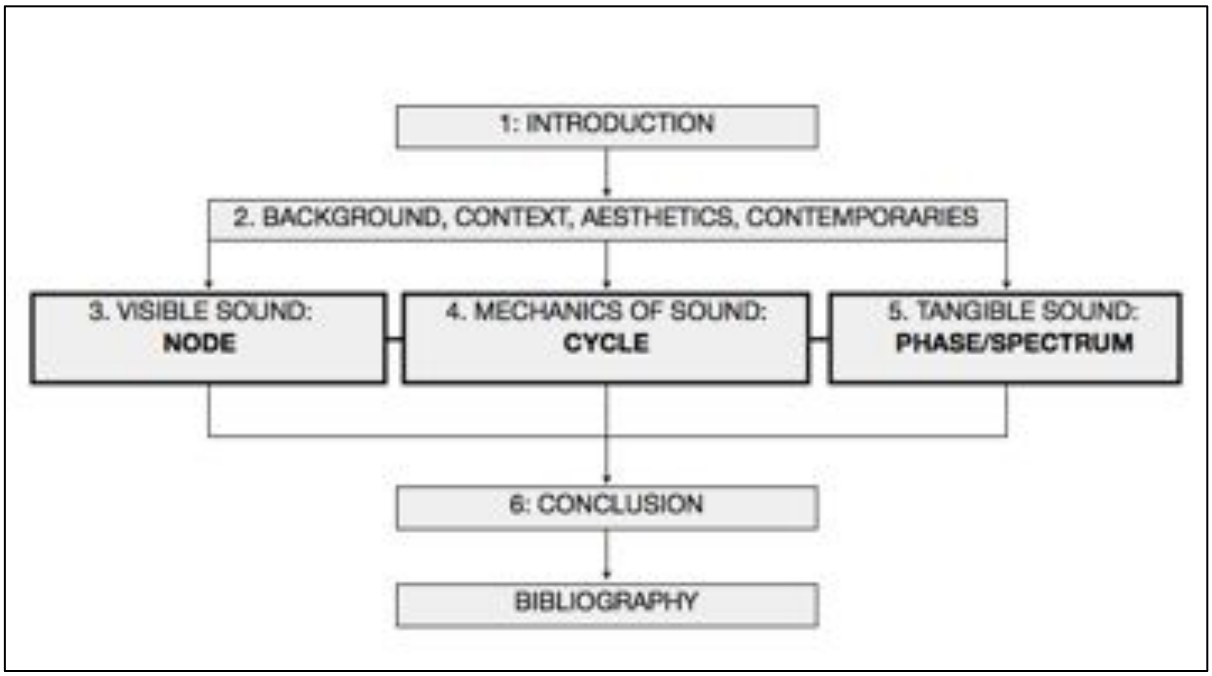

Figure 6: Thesis Outline

Visualizing sound and vibration through a physical medium is the basis for the work *NODE* (Chapter 3). This piece is *directly* representative of what sound actually looks like from a natural, physical perspective. NODE is also about creating a connection between the viewer and nature, something that will be discussed in more detail throughout Chapter 3. For *Cycle* (Chapter 4), I wanted to create a piece that could represent the motion of a sound wave, but utilizing a more *indirect* approach than with NODE. The focus of Cycle was on movement, as it exists in nature. Cycle is a large kinetic sculpture that focuses on the cyclical motion of a mechanical wave. The focus of this work is far more conceptual than with the project NODE, as it is meant to merely represent the fluid cyclical motion of a wave. The key with Cycle was to achieve three-dimensional motion, which would create a more accurate representation of how waves travel in nature. Phase (Series), which is a set of sculptures depicting the complex harmonic spectra of sound (Chapter 5), utilizes a hybrid approach to conceptualizing natural sonic content. This project deals primarily with natural structure. First, the actual frequency spectrum of a specific piece of audio is analyzed, and the various harmonic components of the sound are stored into a data table. Next, the data is conditioned and re-interpreted to allow for the creation of a large static physical sculpture meant to *indirectly* represent the sonic "fingerprint" of the analyzed audio – a physical, tactile manifestation of a spectral FFT waterfall plot. In each of these three examples, the primary artistic focus is on the translation of natural phenomena as a means to invoke a sense of *connectivity* to nature, as well as to relay a visible and/or sonic representation of the complex *movement* and *structure* of sound.

Table 1: Overview of Thesis Projects (Influence + Theme)

PROJECT	**NODE**	**Cycle**	**Phase (Series)**
INFLUENCE	*Direct*	*Indirect*	*Both*
THEME	*Connectivity*	*Movement*	*Structure*

Chapter 2

A Historical & Contemporary Context

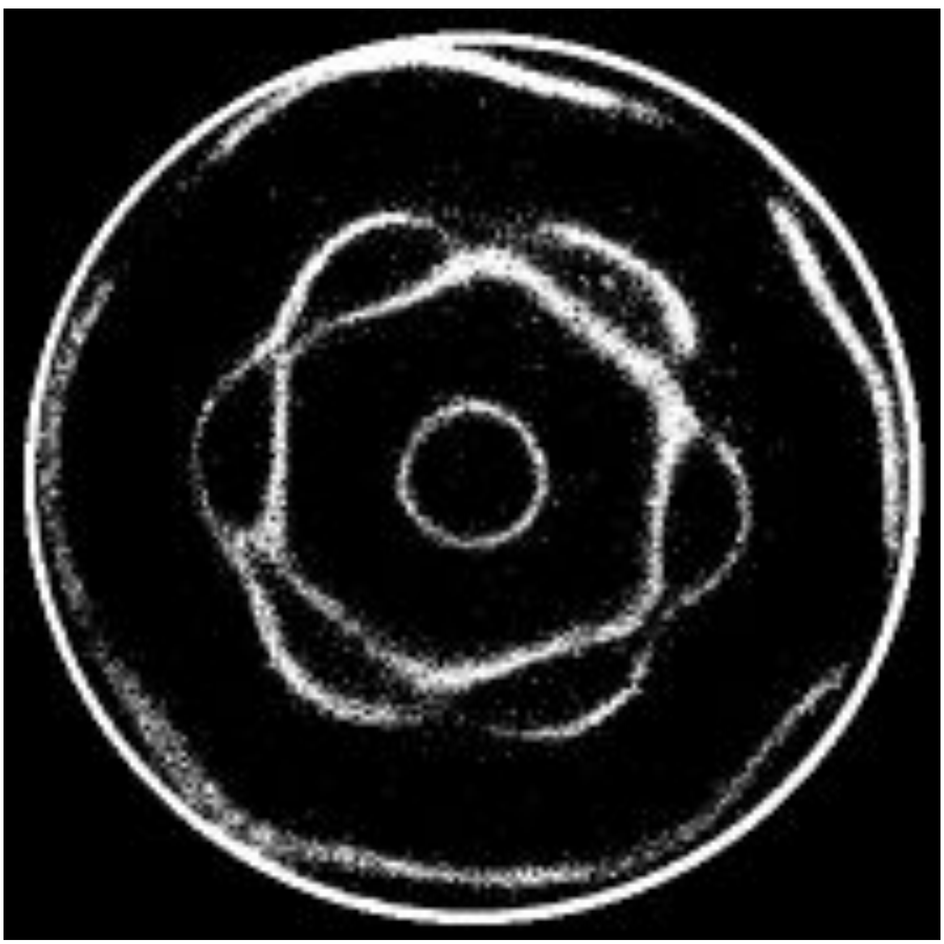

Figure 7: A Chladni Plate

2.1 Chapter Overview

The basis for the work presented in this thesis stems from a multitude of different approaches to art, in terms of aesthetics, style, and presentation. In order to provide a relevant context for these projects, the following chapter will center on the examination of various contemporary artists and their work that has influenced my creative process. Many artists have influenced my work from a multitude of perspectives. In general terms, I have a tendency to be drawn towards art that has a natural motif – whether that influence is *directly* or *indirectly* linked to nature. Work that expresses a mechanical or structural component of nature, or work that simply utilizes a natural setting, relying on parameters such as scale, or natural phenomena to actualize the piece. In this chapter, I will first examine three distinctive works that have influenced my aesthetic, and have additional relevance to this thesis in terms of an underlying focus on nature and natural systems. Later in the chapter, I will focus specifically on artists who have created similar work to the projects detailed in this thesis, from a scientific, historical, and contemporary context, in terms of Cymatics, Kinetic Art, and Sculpture/Generative Art.

2.2 Walter De Maria *(The Lightning Field – 1977)*

Walter De Maria was an American sculptor and conceptual artist known primarily for his contributions to the Land Art movement of the 1960's. His work focused on immersive, large-scale sculpture directly linked to natural settings, as well as natural phenomena. His work *The Lightning Field (1977)* is an ongoing permanent installation set in a remote area of western New Mexico. [12] The work comprises of a massive array of 400 steel poles, each measuring 20 feet in height, imbedding in the desert floor. The work is spread out over a rectangular mile, with each pole separated by a distance of 220 feet. These poles function as large lightning rods, and during thunderstorms, attract an impressive display of lightning events, which can be safely viewed by a visitor from a covered location. The shear scale of *The Lightning Field,* along with the visceral and unpredictable nature of the work, invokes a sense of controlled chaos – a person's attempt to control nature – and effectively places the natural phenomenon of lightning within an artistic context. De Maria's *direct* approach to examining natural phenomena gives the viewer a sense of connectivity with their natural surroundings by creating the *illusion* of control. An additional

[12] http://www.diaart.org/sites/main/lightningfield

dynamic of this work stems from the concept of "potential". Based on the fact that the artist cannot control when and where a lighting storm may occur, the work's *potential* alone provides a necessary relevance, even in the absence of inclement weather.

Figure 8: Walter De Maria's "The Lightning Field" (1977)

2.3 Jem Finer *(Score for a Hole in the Ground – 2006)*

Jem Finer is a musician and installation artist, known primarily as one of the founding members of the British punk band *The Pogues*. In 2005, Finer created a permanent sound installation piece in the middle of Kingswood forest in Kent, England titled *"Score for a Hole in the Ground"*.[13] The installation consists of a 7m (meter) deep, waterproof concrete shaft imbedded in the ground, much like a large well. The shaft is filled with a series of various percussive objects, such as

[13] http://www.scoreforaholeintheground.org

metallic bowls and metal plates. The top of the shaft is covered in a large steel-slatted grate, surrounding a massive iron acoustic horn that protrudes out from the shaft. The horn functions

Figure 9: Jem Finer's "Score for a Hole in the Ground" (2006)

as an acoustic amplifier for the sound coming from within the well. The topography of the area around the shaft was sculpted into a pond-like shape in order to collect rainwater, which could be directed down through the grating and into the shaft. This installation functions as a *natural generative musical system* when drops of water fall into the shaft and strike one of the percussive objects below. The array of metal objects installed at the base of the shaft create a wide range of interesting percussive and melodic tones, which can be heard from anywhere around the piece. By letting nature effectively become the performer, this *direct* approach to natural phenomena creates a unique and powerful artistic statement. When describing the work, the artist stated *"This piece of music depends neither on the longevity of any energy source or technology, only on the ongoing existence of the planet and its weather systems."* [14]

[14] http://www.scoreforaholeintheground.org/?page_id=14

2.4 Ryoji Ikeda *(Superposition – 2012)*

Ryoji Ikeda is a Japanese sound and visual artist, whose work focuses on duality, binary systems, and various extremes of human perception. Ikeda's work "Superposition" is a large-scale, highly immersive performance that explores the reality of nature on an atomic scale. Based on various

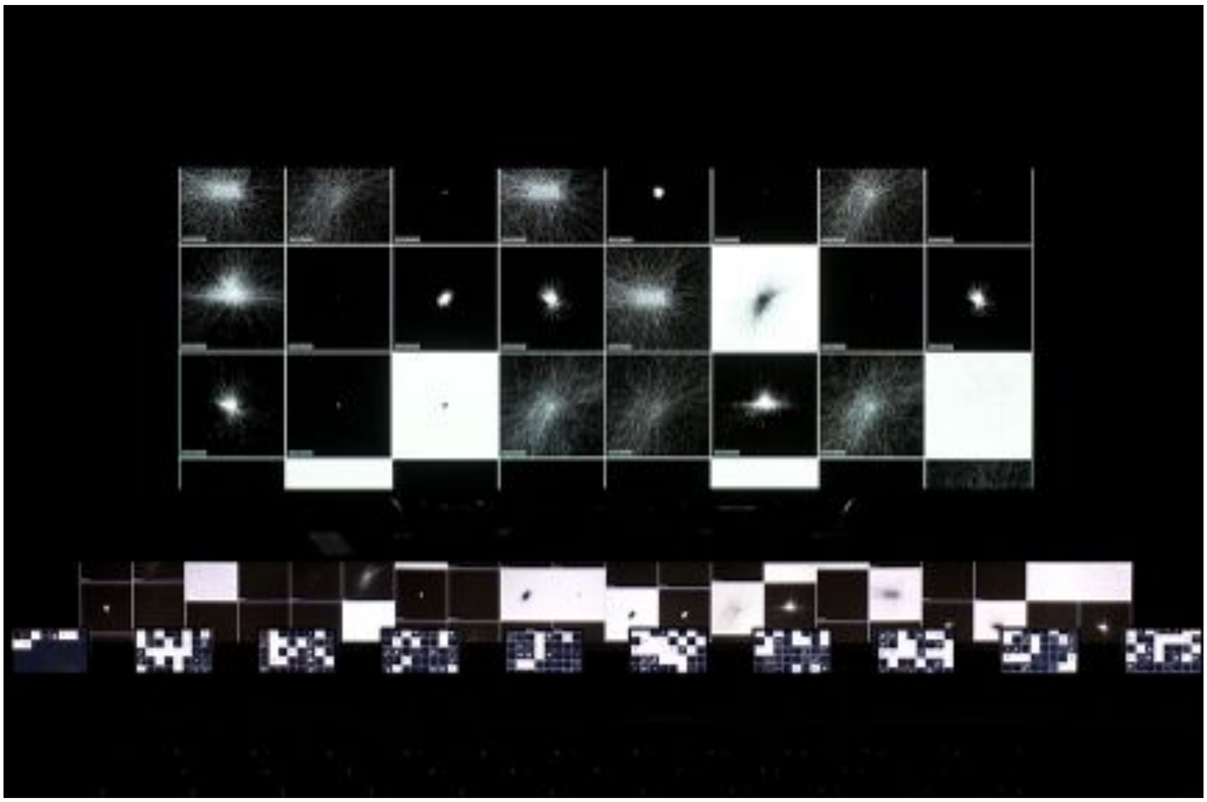

Figure 10: Ryoji Ikeda's "Superposition" (2012)

concepts of physical phenomena, mathematics, and quantum mechanics - most notably the laws of superposition, binary states, and quantum duality, "Superposition" takes an *exhaustive* approach to examining unseen natural concepts through a multitude of different sonic/visual motifs. [15] The work itself is highly literal, where every component associated with each piece reflects a *superposition* state. Superposition utilizes a combination of visual and sonic elements to convey the concept of duality in nature, including the use of two performers through various forms of interaction. The work itself, however, is almost exclusively linked to technology, utilizing computers to generate complex visuals, sound and light – even the performers

[15] http://www.ryojiikeda.com/project/superposition/

themselves contribute through the use of telegraph machines, code-breaking algorithms to generate random sonic events through dual-state interfaces. During a set moment of the work, a series of phrases depicting duality start to appear on a large screen behind the performers. One of the phrases, a quote from philosopher Ludwig Josef Wittgenstein [16], states *"Logic is not a body of doctrine but a mirror image of the world."* The exploratory aspect of the work, including the desire to find a multitude of approaches to express one central idea, is a concept I find very appealing and influential. Additionally, the focus on unseen natural phenomena, and the various approaches used to translate those ideas through *indirect* means, provides a solid foundation for which my work is based.

2.5 Modal Phenomena

Modal Phenomena, also known as *Cymatics* [17]*,* has been explored for centuries, first documented by *Galileo* in 1632, and later expanded on by *Robert Hooke* in 1680. [18] *Ernst Chladni (1756-1827),* a German physicist and a pioneer in experimental acoustics, expanded the study of modal phenomena by inventing a technique for visualizing modes of vibration on a solid surface. [19] The *Chladni Plate,* as it is now referred to, consisted of a large metal plate connected to a fixed point and then lightly covered with sand. Chladni would excite the edge of the metal plate with a violin bow, causing the plate to resonate. The vibrations themselves would cause the plate to divide into regions that vibrate in opposite directions, creating distinctive patterns within the sand where no vibration occurred. These *nodal lines* would occur along the *standing waves* where there was minimum amplitude. [20] These various points in the standing wave, referred to as *nodes,* change based on the resonant frequency of the physical vibrating surface, in addition to other acoustic properties that can create additional harmonics. These *nodes* occur at intervals of half a wavelength ($\lambda/2$). [21] Halfway between two nodes are areas where the amplitude of the standing wave is at a maximum. These *antinodes* are the points where the two waves add together, and the amplitude is determined by the phase relationships between the waves. (Chladni's research into this phenomenon, called *Chladni figures,* was detailed in his dissertation, *Die Akustik* - which was

[16] http://www.britannica.com/biography/Ludwig-Wittgenstein
[17] http://www.cymatics.org
[18] http://www.cymascope.com/cyma_research/history.html
[19] http://americanhistory.si.edu/science/chladni.htm
[20] http://www.physicsclassroom.com/mmedia/waves/ipd.cfm
[21] http://www.qrg.northwestern.edu/projects/vss/docs/communications/2-how-are-frequency-and-wavelength-related.html

published in Germany, 1802). *(Chladni 1830)* Chladni's research is still used today by acoustic instrument makers who utilize the same technique to isolate and identify the various 'modes" of vibration which allows for proper acoustic design.

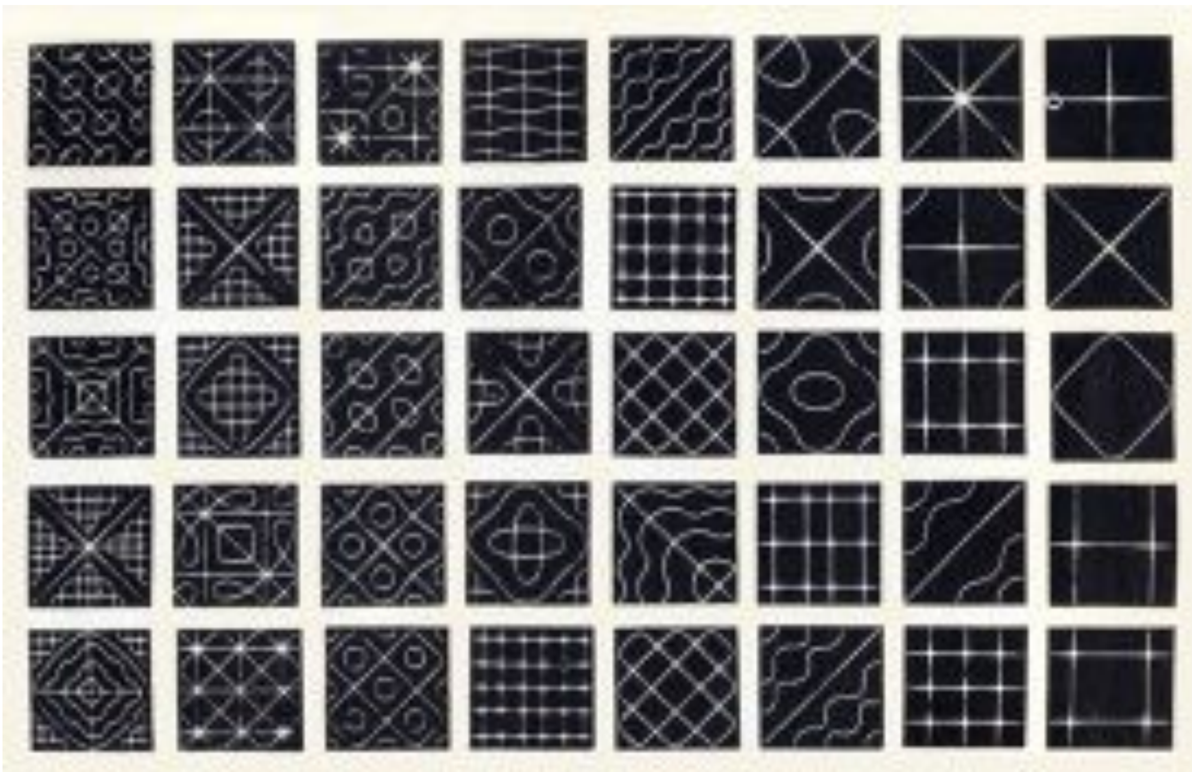

Figure 11: Chladni Figures

2.5.1 Dr. Hans Jenny + Cymatics

Another influential figure in the realm of experimental acoustics was Dr. Hans Jenny (1904 - 1972), a Swiss physicist who coined the term *Cymatics,* which is now synonymous with the study of modal/wave phenomena. [22] Jenny's research involved the use of tone generators and crystal oscillators connected to metal plates, which allowed for precise control over both amplitude and frequency of the signal. In addition to approaching Cymatics utilizing the *Chladni* method, Jenny also started exploring the use of liquids along with loudspeakers to generate these complex patterns. This new approach yielded results that were highly detailed, and also allowed for

[22] http://www.cymatics.org

visualization of continuous motion, something that the Chladni figures could not achieve. Jenny's work was documented in his book *Cymatics: A Study of Wave Phenomena and Vibration (1967).* (Jenny 2001)

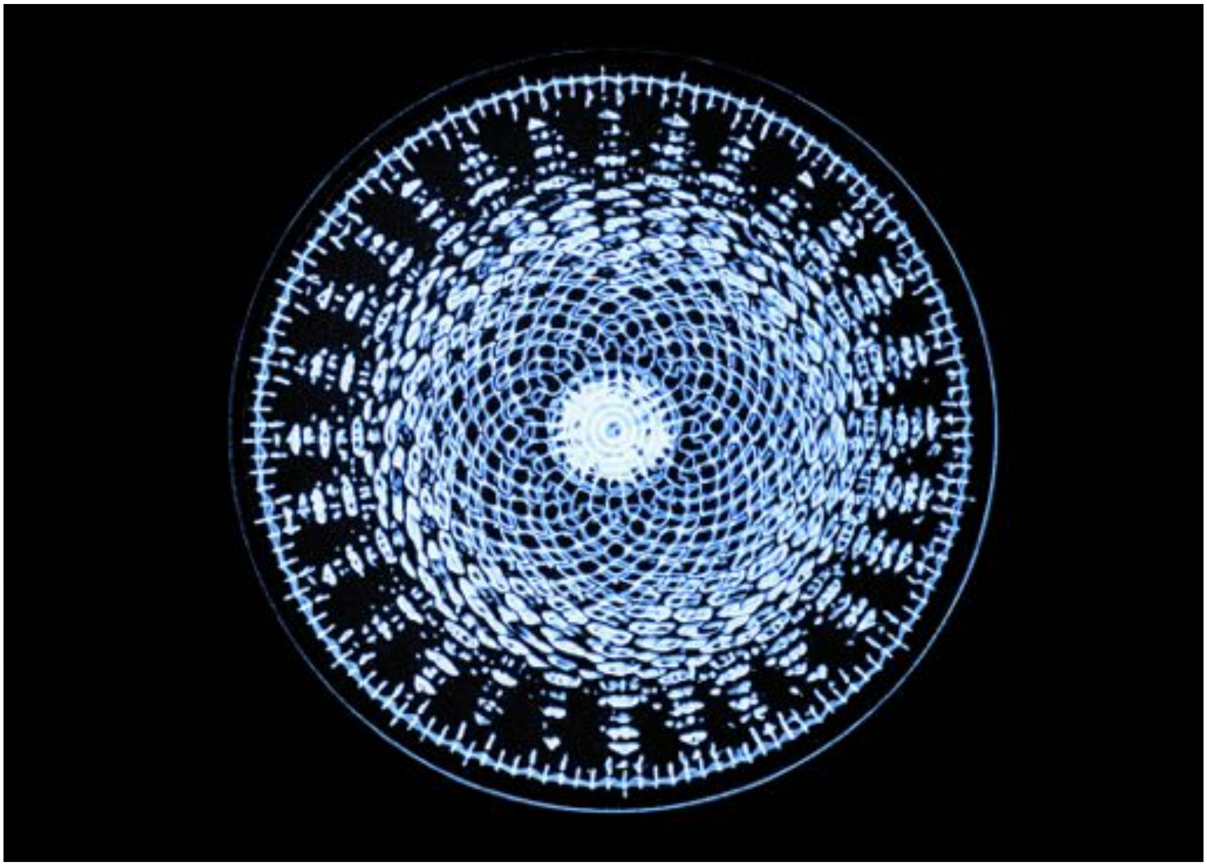

Figure 12: Cymatics Ex. in Water (Microphotography)

2.6 Cymatics in Art

The use of Cymatics in art has been well documented since the early 1970's. However, artists and musicians have been interested finding ways to visualize sound since the beginning of the 20th century. A number of audio-visual experiments took place during the 1950's that focused on finding connection between color and sound, primarily within the field of visual art. Many of these experiments were designed around the concept of *color synesthesia*, and were created to elicit *synesthetic* experiences for a general audience. Experimental composers such as *Edgard Varèse (Poème Electronique - 1958)* created work that was meant to invoke connectivity between what was visible and what was audible. ("Visualizing Twentieth Century Sound Art Objects" 2016) Upon the release of Hans Jenny's research regarding *Cymatics*, composers such as *Alvin Lucier* began constructing musical pieces inspired by Jenny's techniques of producing modal phenomena. In Lucier's piece *The Queen of the South (1972),* the composer gives illicit instructions to the performers for creating visual modal feedback:

"Sing, speak, or play electronic or acoustic musical instruments in such a way as to activate metal plates, drumheads, sheets of glass, or any wood, copper, steel, glass, cardboard, earthenware, or other responsive surfaces upon which are strewn quartz sand, silver salt, iron filings, lycopodium, granulated sugar, pearled barley or grains of other kinds, or other similar materials suitable for making visible the effects of sound." [23]

At the start of the 21st century, sound and visual artist *Carsten Nicolai* created a series of pieces focused on the study of Cymatics. His work *Milch (2000)* was a series of still images printed on aluminum that focused on capturing modal phenomena in milk, generated by sine waves between 10 to 150 Hz. [24] Nicolai's work *wellenwanne (2001),* utilized four large trays filled with water, each resting on loudspeakers. A series of sound recordings, only partially audible, were played through the speakers, creating various interference patterns in the water. [25]

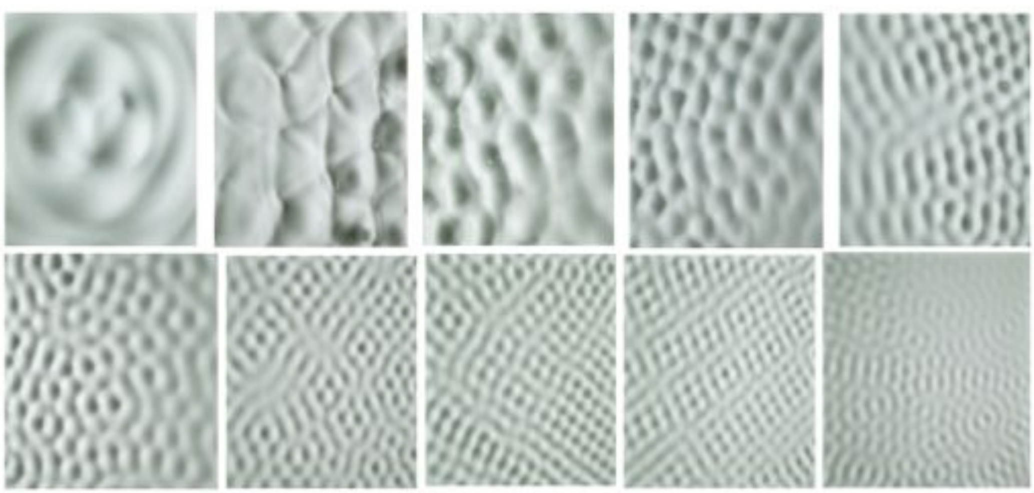

Figure : Carsten Nicolai's "Milch" (2000)

[23] http://supanickblog.blogspot.com/2011/07/alvin-luciers-queen-of-south.html
[24] http://www.carstennicolai.de/?c=works&w=milch
[25] http://www.carstennicolai.de/?c=works&w=wellenwanne

2.6.1 Additional Work

In 2011, Icelandic artist *Björk*, in collaboration with visual artist *Evan Grant,* created real-time Cymatics visuals to coincide with the performance aspects of her concept album '*Biophilia'*, generating modal patterns on a Chladni plate covered in salt, and projecting the patterns on a large screen behind the performers. The patterns on the Chladni plate were generated using the audio from the low frequency sonic material of Bjork's music during the performance. [26] Over the past decade, many other artists such as Thomas Mcintosh *(Ondulation – 2007)*[27]*,* Finnbogi Petursson *(Infra.Supra - 2014)*[28]*,* and Elizabeth Ogilvie *(Bodies of Water - 2005)* [29] have produced large-scale installations utilizing Cymatics to create immersive sonic and visual experiences. Their work has played a quintessential role in pushing the boundaries of the fusion of sonic art and natural phenomena.

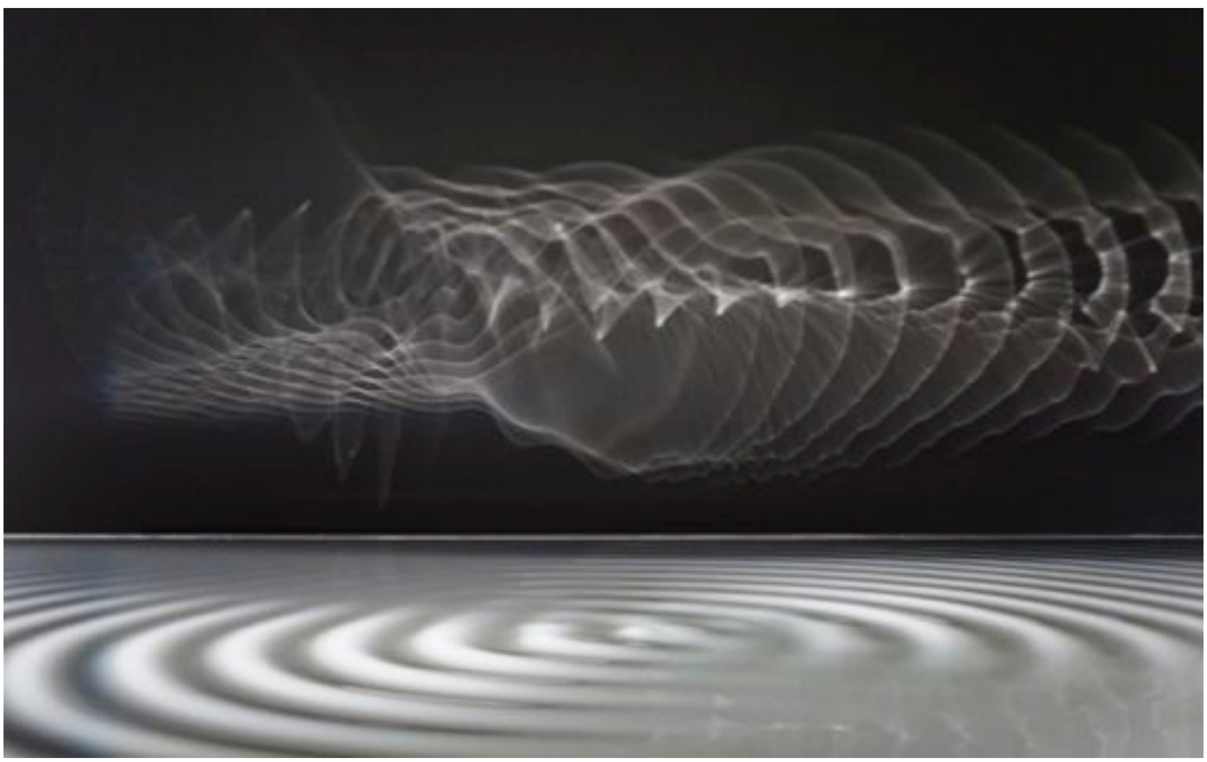

Figure 13: Thomas Mcintosh "Ondulation" (2007)

[26] http://www.biophiliathefilm.com

[27] http://www.fondation-langlois.org/html/e/page.php?NumPage=35

[28] http://bombmagazine.org/article/2000040/finnbogi-petursson-s-em-second-second-em

[29] http://www.elizabethogilvie.com/proj_uploads/bow.pdf

2.7 Kinetic Art

Kinetic Art, in a contextual sense, started developing in the early 1920's as a progression of the *Constructivist* and *Dadaist* movements. Artists such as Naum Gabo *(Standing Wave - 1919),* who coined the term *kinetic art* in 1920, and Marcel Duchamp *(Bicycle Wheel - 1913, Rotary Demisphere - 1925),* were responsible for inspiring work associated with movement. These artists helped to pave the way for further exploration of motion in art. In the 1930's, *Bauhaus* artist Laszlo Moholy-Nagy created the kinetic work *Light Space Modulator,* which consisted of three motorized, moveable metal structures arranged on a rotating discs, lined with various colored lights. The piece was initially created as a theatrical tool, but is now considered an important early work of kinetic art. [30]

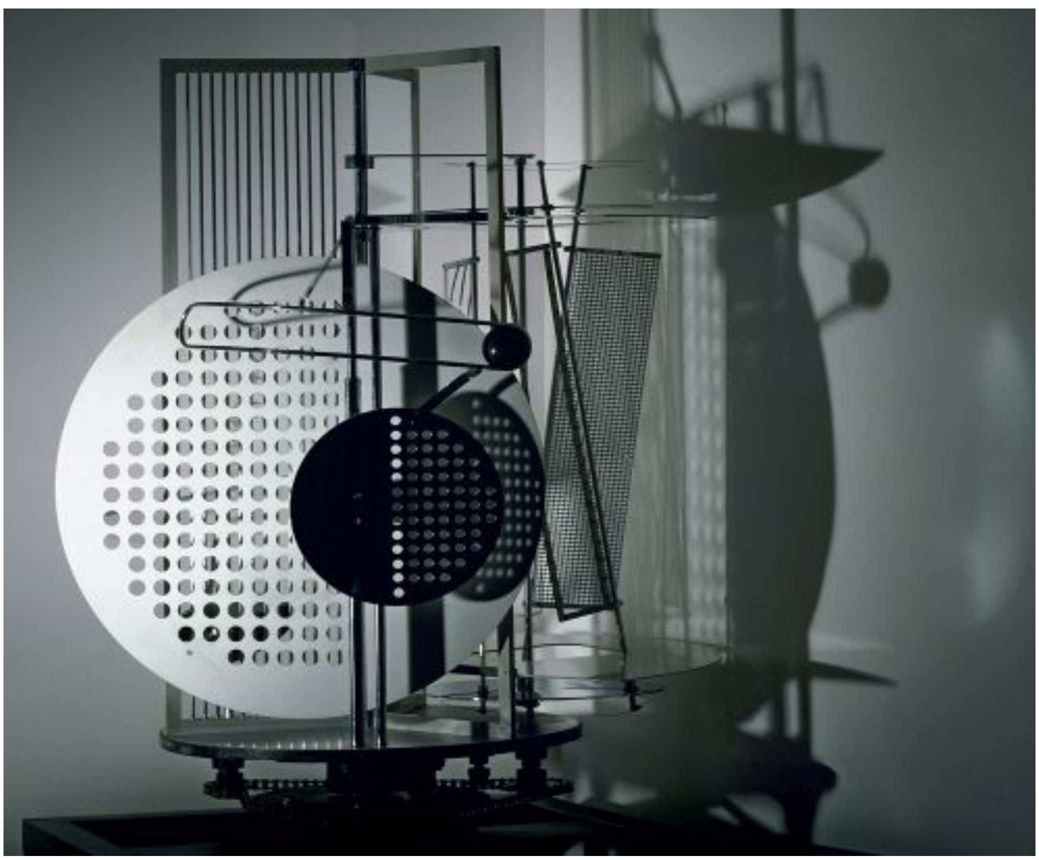

Figure 14: Light Space Modulator

[30] http://www.theartstory.org/movement-kinetic-art.htm

2.7.1 Le Mouvement - 1955

The Kinetic Art movement gained substantial notoriety during the 1950's, in part, due to the "Le Mouvement" exhibition, which was held in the *Galerie Denise René* in Paris in 1955. The theme of the exhibition dealt with *movement as a means of expression,* and featured work from artists such as Jesús Rafael Soto, Robert Jacobson, Jean Tinguely, and Marcel Duchamp, among others. This exhibition, along with the writings of Victor Vasarely *('Yellow Manifesto - 1955')* helped solidify Kinetic Art as a major international artistic movement. [31]

2.7.2 Contemporary Work

Over the last 30 years, Kinetic Art has continued to develop and evolve, benefiting greatly from various technological advances and cost-effectiveness with regards to circuitry, fabrication techniques, and computational power. (Trimpin 2011) Artists such as Trimpin, Theo Jansen, Eric Singer, Jim Murphy, Behnaz Farahi, Zimoun, and Reuben Margolin continue to push the boundaries of Kinetic art, exploring new ways to create stunning work utilizing mechanics and motion through sculpture, performance, and installation art.

Figure 15: Trimpin's "IF VI WAS IX"

[31] http://artdaily.com/index.asp?int_sec=2&int_new=36163

2.8 Sculpture + Generative Art

The practice of sculpture has existed for thousands of years.[32] Since the dawn of human history, there has been a desire to create tangible three-dimensional artifacts that reflect our experiences, beliefs, and ideas, reproducing things both familiar and non-familiar as a means of artistic expression.[33] More recently, the advent of various methods of digital fabrication, has aided artists in actualizing physical manifestations of work that would otherwise be impossible. This paradigm shift in fabrication techniques, along with the continual improvement of 3D modeling and Computer Aided Design (CAD) software, has changed the face of sculptural art and architecture, allowing artists who work within the context of digital art to bridge the gap between what can be generated on a computer and what can be built in the physical world.[34] Artists such as Casey Reas, Teresita Fernández, Zaha Hadid, Monica Ponce De Leon, Erwin Hauer and Lisa Iwamoto have explored various methods of generative and computational techniques to create sculptural work that is pushing the boundaries of what is possible in terms of constructing forms.

Figure 16: Lisa Iwamoto's "Jellyfish House" (2005)

[32] http://www.nytimes.com/2009/05/14/science/14venus.html?_r=0

[33] http://www.scholastic.com/browse/article.jsp?id=3753866

[34] http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10452157

Chapter 3

Visible Sound: NODE

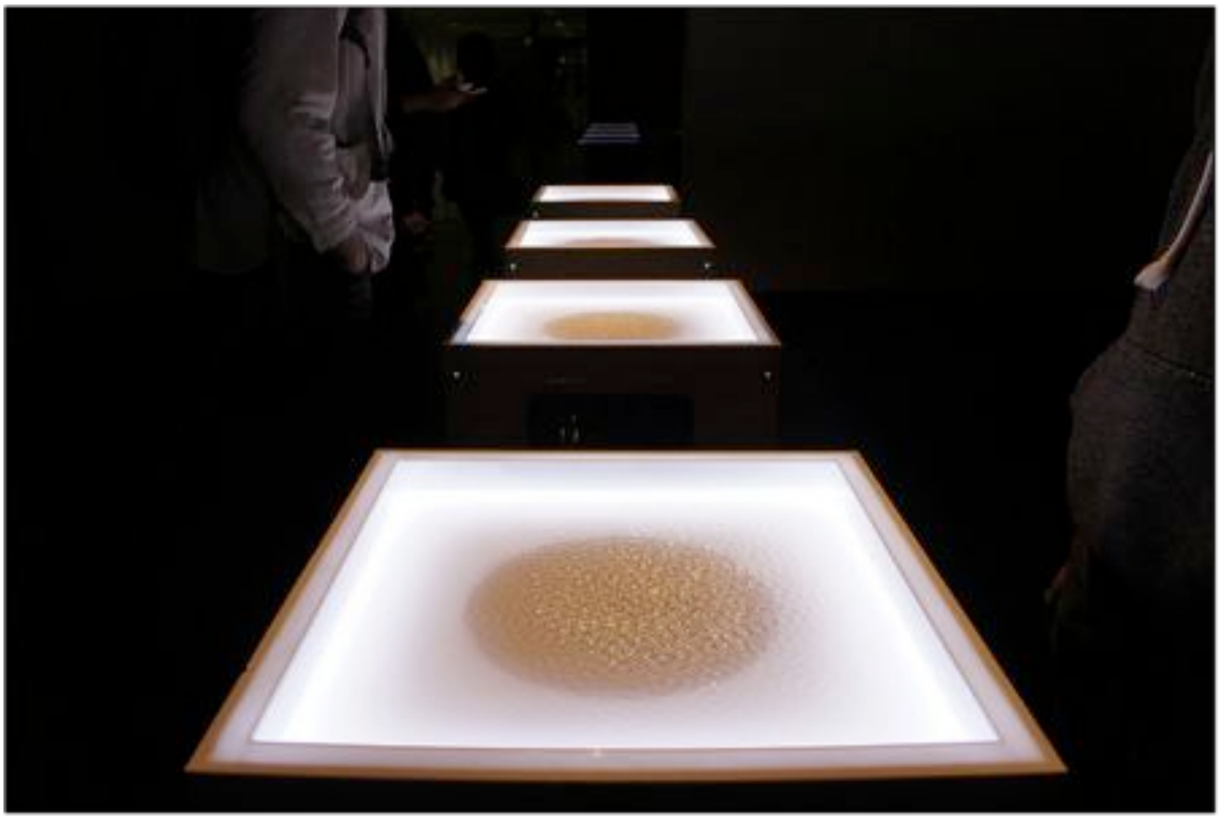

Figure 17: NODE Installation - (2015)

"This is not unregulated chaos. It is a dynamic, but ordered pattern." - *Hans Jenny, 1967.*

3.1 Project Synopsis

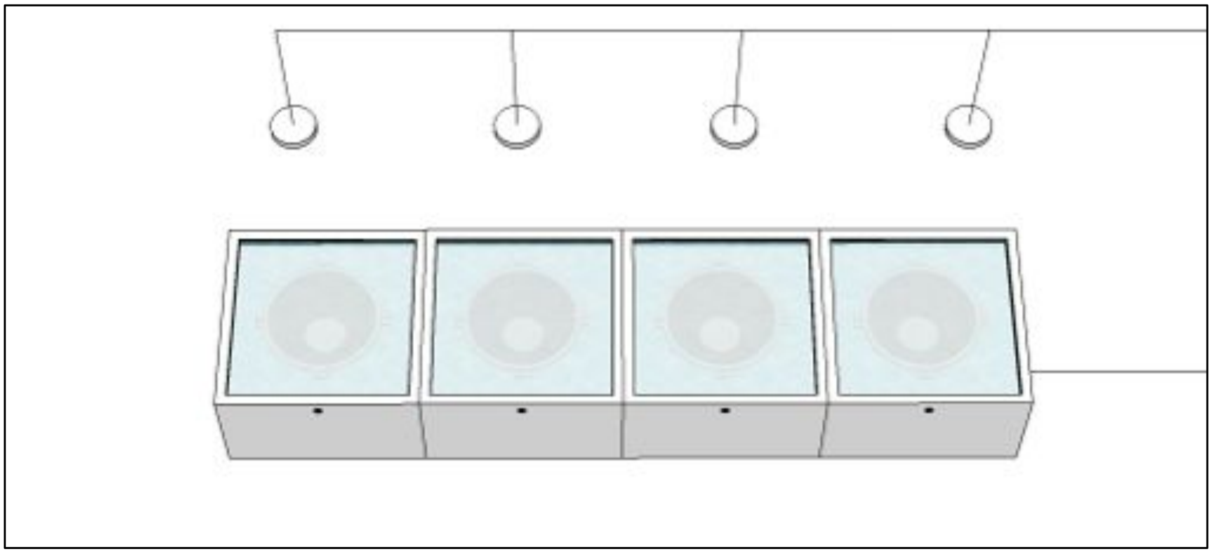

Figure 18: NODE Rendering

NODE is a reactive real-time audio/visual installation that centers on the concept of *Cymatics* (modal phenomena), which is *the study of visible sound and vibration*. Within the space, there are four large, identical cubes, each separated by 2 feet. At first, these cubes sit stagnant and appear to serve no real function. However, once a visitor approaches a cube, the cube slowly activates, lighting up and revealing a basin of water. At the same time, a low frequency tone starts to emanate from within the cube. As the tone gets louder, the liquid at the surface starts to react and complex, fractal-like patterns start to form on the surface. The sound from the cube is then re-enforced by surrounding satellite speakers that reproduce a higher equivalent fundamental frequency of the original tone. Each cube functions as a discrete system, so as the visitor approaches a different cube, the first cube slowly fades out and the new cube activates, creating a different tone with a different complex pattern. However, the cubes are also interlinked. Therefore, if two people interact with two different cubes, both cubes will begin modulating one another, affecting the sonic and visual outcome. If all four cubes are activated, the patterns and sound generated becomes much more chaotic and unstable. It is possible, for example, to be in the space watching this event and not realize there is any reactive or interactive component to the piece until someone abandons a cube. At that point, the abandoned cube slowly begins to fade out and all of the remaining cubes that are still active become less chaotic, more clearly defined.

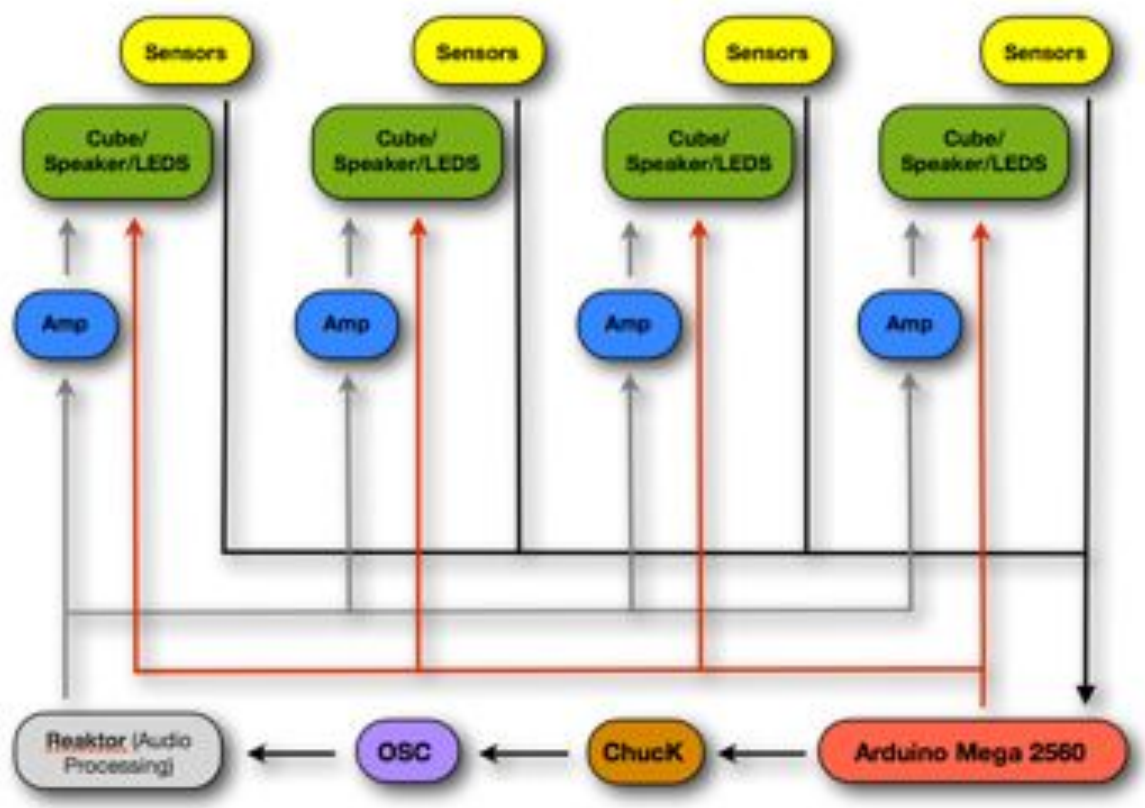

Figure 19: NODE Signal Flow

Essentially, NODE works like a large, interactive *FM synthesizer,* where each cube functions exactly like an "*operator"* in FM synthesis, with the ability to generate its own tone, as well as to modulate another.[35] This "morphing" that occurs when more than one person is viewing the piece is a key element in terms of the interactive component of NODE. The ability for someone else to impact what you, as a viewer, are experiencing gives the piece a social component that will be discussed later in the chapter. Since the patterns that occur in the liquid are directly related to the sound being generated, the viewer gets a window into what the sound actually looks like. NODE provides the viewer with unique insight into the invisible world of

[35] https://people.ece.cornell.edu/land/courses/ece4760/Math/GCC644/FM_synth/Chowning.pdf

mechanical waves, as they exist in nature. The more harmonic complexity within the sound, the more complex the patterns become. (Jin Oh 2012)

3.2 Project Concept

The purpose of this installation is to show clear visible relationships between acoustic signals and modal phenomena, allowing visitors to experience what is normally beyond their scope of vision - in this case, the beauty and complexity of mechanical waves that exist throughout nature. More specifically, we typically visualize sound, whether in terms of time (oscilloscope) or frequency (spectral/fft), by way of mathematical approximation. Because *modal phenomena* exist in nature, it provides an actual view into what sound looks like when traveling through a physical medium.

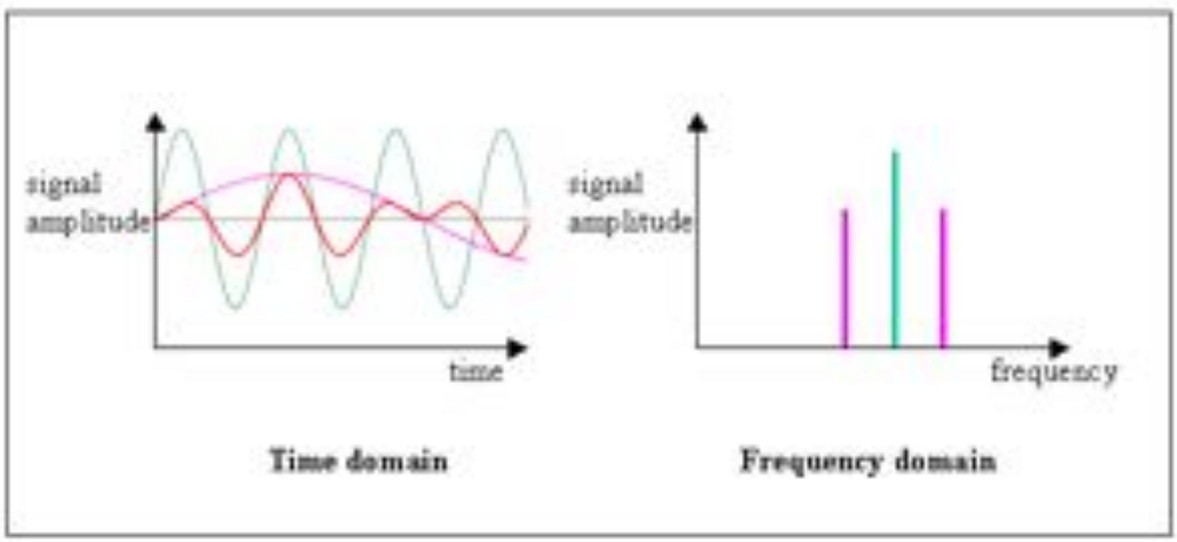

Figure 20: Time Domain & Frequency Domain

3.2.1 Reflection of Society

NODE was designed as an attempt to create a piece that is indicative of a sort of chaotic order within a controlled and inherently deterministic system - one that is both complex, yet repeatable. In a way, the visitors become a larger part of that system. Much like in a society, the more people interacting with the piece, the more complex and chaotic the installation becomes. NODE was additionally designed to give groups of people different experiences. For instance, if only one person interacts with the installation, the complexity of the patterns and sound that emerge is limited to just a single event. This is conceptually symbolic of people's ability to be alone with their thoughts. One cube creates a hypnotic state represented by a single sine wave, creating a calm and repeating pattern. However, if a second person interacts with the installation, both the sound and the patterns that occur become more complex, making it more difficult to see the visitor's individual voice within the piece. This continues until both the patterns and the sound hit a saturation point and the individual becomes lost in the noise and complexity of the system. By learning how the system functions, the visitors might interact in such a way as to control the outcome, creating a large harmonically powerful event. When considering NODE and the nature of physics, there are many obvious parallels between these complex, repeatable events and how human beings interact in society, existing within the framework of a social order, and how we as a society tend to follow patterns within a social construct. This sense of *connectivity* between social and natural order is the basis for the interactive elements of NODE. In a strictly utilitarian sense, NODE is a large, fully functional synthesizer, where the visitor becomes the performer, and the performance itself becomes a form of social interaction.

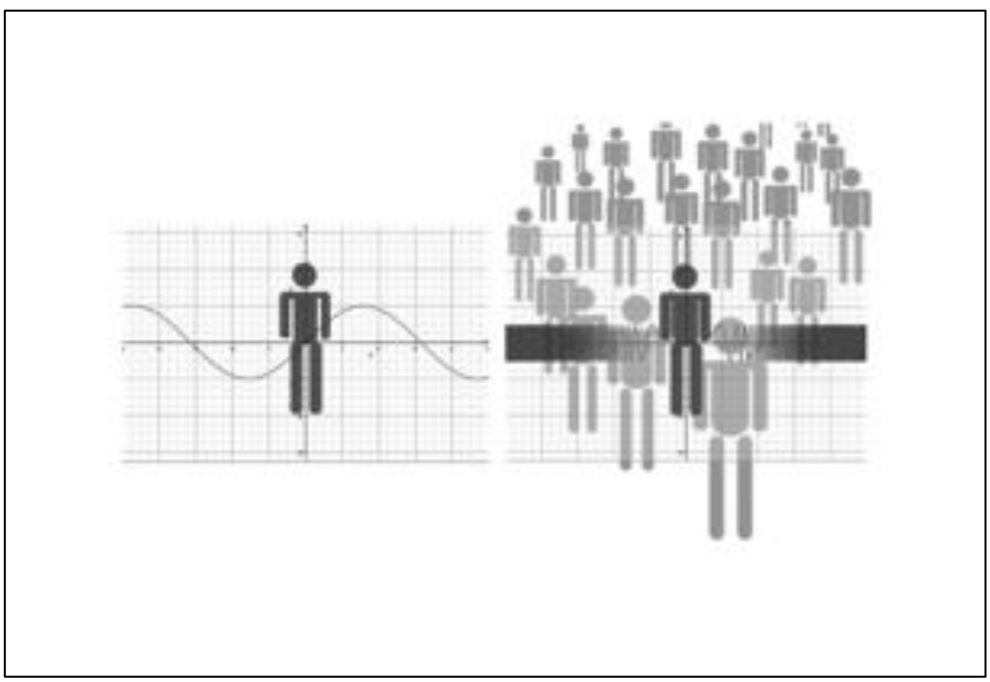

Figure 21: Individual vs. Group

3.2.2 Chapter Description

In this chapter, the installation NODE will be presented and discussed with regards to the initial conceptual framework, evolution and completion of this project. Additionally, there will be an explanation of the technical aspects of this work, including details regarding software, sensors, and fabrication techniques, as well as discussion with regards to the various roadblocks faced throughout the process of completing this project. Finally, there will be a quick look at the possibility of future work that relates to NODE and the exploration of *modal phenomena*.

3.3 Previous Work in Cymatics

The NODE installation was conceptualized in the spring of 2014. During that time, I spent numerous hours experimenting with modal phenomena. Initially, the goal was to create a piece for real-time pattern generation that could be projected during a performance. This work culminated into two separate presentations of pieces involving modal phenomena and the use of phase modulation/FM synthesis: the first being presented at California Institute of the Arts during the institution's *Digital Arts Expo: 2014*. The second adaptation was presented at *NMASS: 2014* in Austin, Texas. Both pieces involved the creation of interference patterns utilizing *Frequency Modulation* synthesis. With FM Synthesis, complex harmonics (sidebands) are created by modulating the frequency of an oscillator (carrier) with the output from another oscillator (modulator). (Chowning 1986) In terms of Cymatics, utilizing FM synthesis to create interference patterns generated very interesting results. To explore this further, I built a large, watertight box and installed two equidistant 8" speakers directly underneath a 1/4" sheet of acrylic. The two speakers were connected to a large bi-plate 2-channel amplifier, which was connected to a laptop running Reaktor software. By *cross-modulating* two oscillators, each with its own discrete output to a speaker, I could create very unique "phasing" patterns in the water, where the fractal patterns would roll between one speaker and the other. The physical and visual aspects of this interference were very intriguing, and the results of this experiment led me to focus on utilizing FM synthesis in generating modal phenomena. The piece *Phase Modulation (Series)* was a direct result of this combination, as well as a direct precursor to the NODE installation.

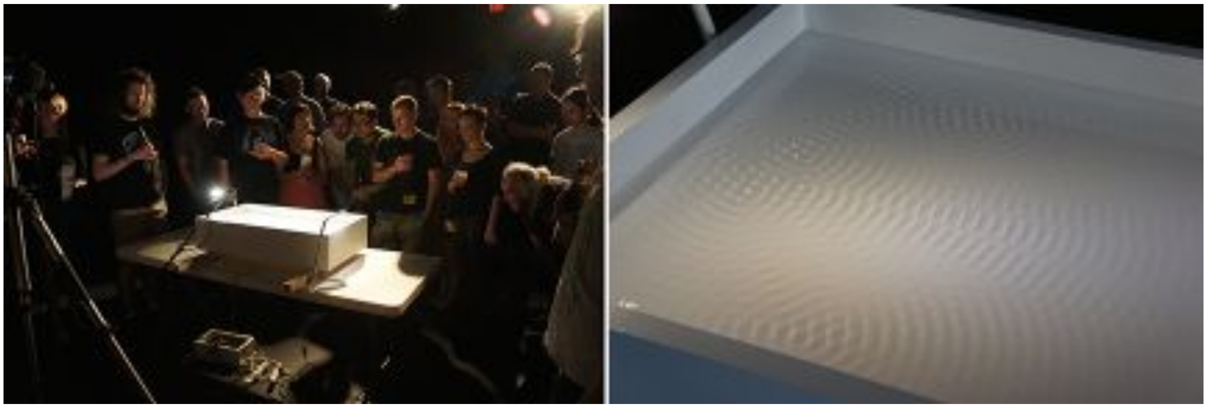

Figure 22: Phase Modulation (Series) - NMASS (2014) & DAE (2014)

3.4 Technical Aspects of NODE

NODE is an interactive, real-time sonic/visual installation that focuses on Cymatics. For this installation, the material chosen to visualize sound waves through was water. When vibration is passed through a physical excitatory medium, the relationships between minimum and maximum displacement are made visible and complex, fractal-like patterns emerge. This installation utilizes four large white birch digitally fabricated (CNC Routed) plywood cubes set up in a row. Most of the components in this work were designed and drafted in AutoCAD, converted to CAM software, and then digitally fabricated with the CNC router. All additional components were fabricated using traditional methods.

Figure 23: Build Process - Cubes & Satellite Speakers

Embedded inside each cube are 10" subwoofers and a two-channel bi-plate amplifier. The subwoofer rests directly underneath the top section of each cube, which is surrounded in 1/8" watertight white acrylic. These acrylic basins are then filled with 1 inch of water. Hidden within grooves of the plywood just below the acrylic are rows of white LED strips. Additionally, there are two ultrasonic sensors embedded on the outside of each cube, one on either side. When the sensors pick up an object nearby, it sends data into an Arduino Mega 2560 micro-controller that activates the LED strips, as well as passes the sensor data into a Mac Mini computer, which is housed inside the base of Cube #1.

Figure 24: Build Process ***continued***

The Arduino serial data is converted to Open Sound Control (OSC) data in ChucK, which is sent to a custom FM patch within NI Reaktor. In addition to storing the primary LED circuit, the Arduino, and the CPU, Cube #1 also contains a 4 channel audio interface, which feeds the audio signal from the computer into the subwoofer within the appropriate cube. The audio interface also feeds signal to 8 custom-built 5-inch satellite speakers, which are placed equidistant from each cube at a distance of 10 feet. The audio generated from the subwoofers is between 20 Hz - 200 Hz. Therefore, the satellite speakers serve to produce additional higher harmonic audio feedback to enhance the sonic experience for the viewer.

3.5 Interactivity

From the beginnings of this project, NODE was designed with the goal of creating a large-scale installation utilizing Cymatics with a plausible, unobtrusive *interactive* component. At the heart of interactive art, there is always the risk for the participatory component of the work to dilute or distract the viewer from the actual meaning of the piece. With the recent rise of inexpensive micro-controllers, sensors, fast processors and open source software, the use of interactivity within the context of installation art has become commonplace. The question that arose when considering an interactive component to NODE was this: *Will the interactivity truly function as a necessary component of the work?* Ernest Edmonds, Professor of Computation and Creative Media at the University of Technology in Sydney, noted *"art becomes interactive when audience participation is an integral part of the artwork. In making interactive art, the artist goes beyond considerations of how the work will look or sound to an observer. The way that it interacts with the audience is also a crucial part of its essence."* (Edmonds 2011) In order to justify interactivity with NODE, there had to be "seamlessness" between the viewer interaction and the work itself. If the interaction took precedence, then it was possible that the primary focus of the work: to show visible relationships between acoustic signals and modal phenomena, would become less clear. The concern with NODE was to not create an interactive component that would end up being a distraction from the true intent of the work, but rather, to invoke a sense of connectivity between the viewer and the work itself. For the purposes of NODE, making the participatory component of the work crucial to the overall functional aspects of the piece solved the issue. This was achieved by interlinking NODE to the concept of *operators* in FM Synthesis.

3.5.1 FM Operators

The basis for FM Synthesis is linked to the interaction of an audio rate *modulator* oscillator and an audio rate *carrier* oscillator. When John Chowning first discovered the algorithm for frequency modulation synthesis in 1967, he wrote, "*The instantaneous frequency of a carrier signal is varied according to a modulating signal, such that the rate at which the carrier varies is the frequency of the modulating signal, or modulating frequency."* (Chowning 1972) By forcing an audio rate oscillator to *modulate* the frequency content of an additional audio rate oscillator, the resulting spectra will contain additional *sideband* harmonics that were not present in the original signals. This relationship (where the modulator oscillator effectively controls the harmonic content of the output signal, and the carrier oscillator controls the amplitude of the output signal) is the basis for FM synthesis. These *"operators"*, or groups of modulators and carriers, can be re-configured in a number of different ways in order to produce a multitude of unique variations in output signal's harmonic spectra. It is common to see groups of 4 operators on an FM synthesizer, where each operator can function as either a modulator or a carrier, based on the selected algorithm.

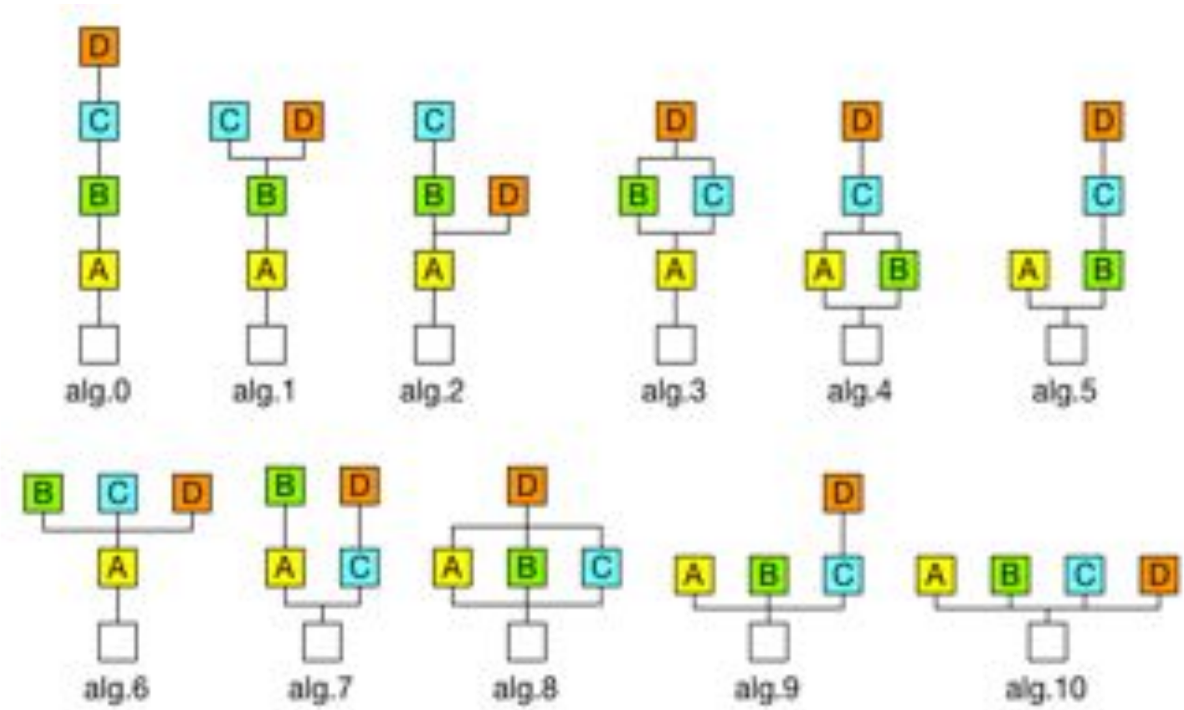

Figure 25: FM Operator Algorithms

The sonic component of NODE is the same. Each cube functions as a carrier when activated. However, the cubes will also cross-modulate each other, depending on which cubes are activated. Because each cube generates a different initial carrier frequency when activated (in order to produce variations in patterns in the water between each cube), the cross-modulation allows for each cube to be modified sonically and visually when additional cubes are active. All of the possible configurations of these algorithms are handled within a custom FM 'Matrix' patch created using NI Reaktor Software.

3.6 Roadblocks

Throughout the process of designing and testing NODE, we experienced quite a few setbacks. Some issues were fabrication-related and required adjustments to a specific component in the design of the cubes. Other issues had to do with the actual functionality of the cubes, powering the various components, lighting, sensors, or with regards to the design of the circuits for controlling the LEDs. Specifically in terms of the overall functionality, there were three primary issues that had to be addressed in order to successfully complete the project. The first issue dealt with the nature of Cymatics and modal phenomena itself. When trying to create a Cymatics system in a liquid that will generate clear visual patterns, there are a few very important factors to consider.

- Amplitude of the acoustic signal
- Fundamental frequency of the acoustic signal
- Resonant frequency of vibrating material
- Amount of liquid
- Liquid viscosity
- Thickness of vibrating material

3.6.1 Primary Issues (Cymatics)

The first set of factors deals with the excitatory medium in which the Cymatics patterns are meant to be viewed. More specifically, the amount of liquid used, and the liquid viscosity plays a large factor in the success of creating visual interference patterns. For NODE, the basins were filled with 1 inch of water. This decision was based exclusively on the desired amplitude of the acoustic signal driving the speaker. Since water has a low natural viscosity, the amplitude envelope of the interference patterns was quite fast. A thicker liquid would hold the pattern shape longer, but the reaction time and clarity would suffer. Any additional water would have required a much larger amplitude signal to generate patterns. So the amplitude of the acoustic signal is inversely proportional to the amount of liquid needed to generate patterns. Additionally, the thickness of the vibrating material also played a huge factor in whether or not patterns would emerge. The second set of factors has to do with the resonant frequency and geometry of the vibrating material, as well as the fundamental driving frequency of the acoustic signal. For NODE, a 2' square sheet of 1/4" acrylic was used to create the water basin. When water was added, only certain fundamental frequencies would generate patterns. Obviously, the closer the audio signal and the resonant frequency corresponded, the more active the patterns would become. This limitation helped to dictate which frequencies were used for NODE.

3.6.2 Primary Issues (Sensors)

An additional issue with NODE dealt with the use of ultrasonic sensors. One specific issue stemmed from crosstalk between sensors that were facing the same direction. Because ultrasonic sensors utilize a 42 kHz ping to measure distance, having multiple sensors facing the same direction initially caused unwanted *ghost* triggers. This issue was resolved partially by connecting the read/write times of the sensors in series. [36]

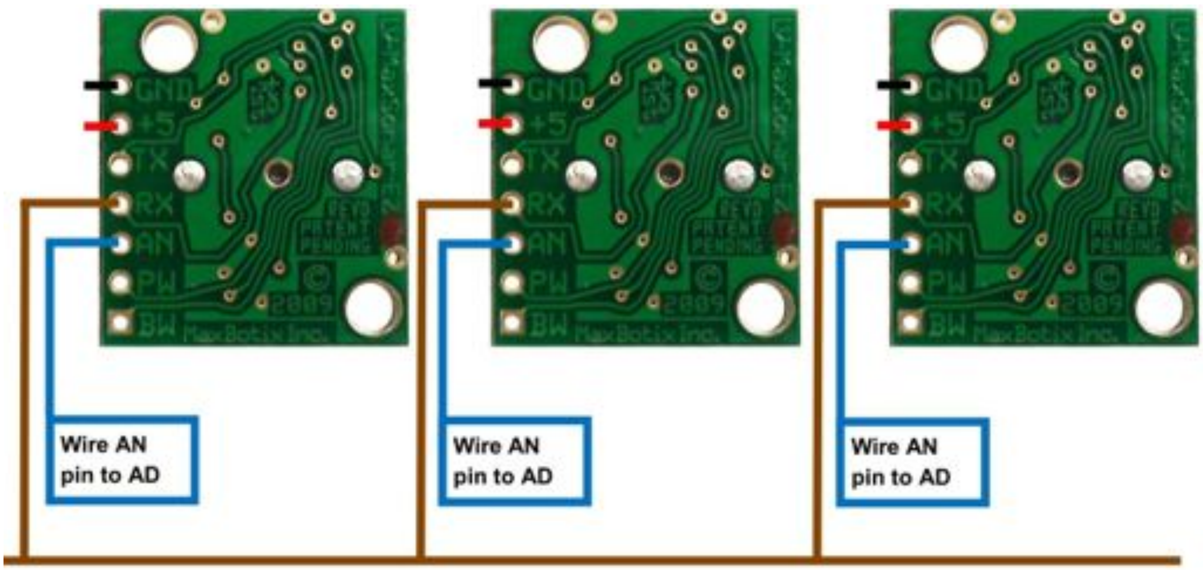

Figure 26: Resolving Issues: Multiple Ultrasonic Sensors

3.6.2.1 Beam Angle of Ultrasonic Sensors

The second issue was the beam pattern angle of the sensors. The sensor detection width measured about 16 inches on either side of the sensor, which dictated to an extent how far apart each cube could be placed without cross-detection. An unforeseen issue encountered during the testing phase of the project was the reflection angle of a sensor ping off a visitor causing nearby cubes to ghost activate. This issue was resolved by adjusting distance between each cube, as well as the sensor's installation depth within the cube, creating a "band-pass wall", embedding the sensor deeper into the cube, in order to limited the sensor's overall range width.

[36] http://www.maxbotix.com/articles/031.htm

3.7 Installation of NODE

NODE was initially installed in the Wave Cave Gallery during the week of the Digital Arts Expo at CalArts in May of 2015. NODE was then presented at the NIME Conference @ LSU during the month of June 2015. NODE is currently under consideration for the 2016 Prix Ars Electronica in the category of Interactive Art +.

Figure 27: NODE Installation - The Wave Cave – CalArts Digital Arts Expo (2015)

3.8 Future Work in Cymatics

The overall experience of creating NODE gave rise to a few interesting potential future projects involving Cymatics. One possible example would be to create a Cymatics installation designed around a live performance, utilizing cameras and light to enhance the audience prospective of the real-time modal phenomena being generated from the sounds being created.

3.9 Documentation of NODE Patterns

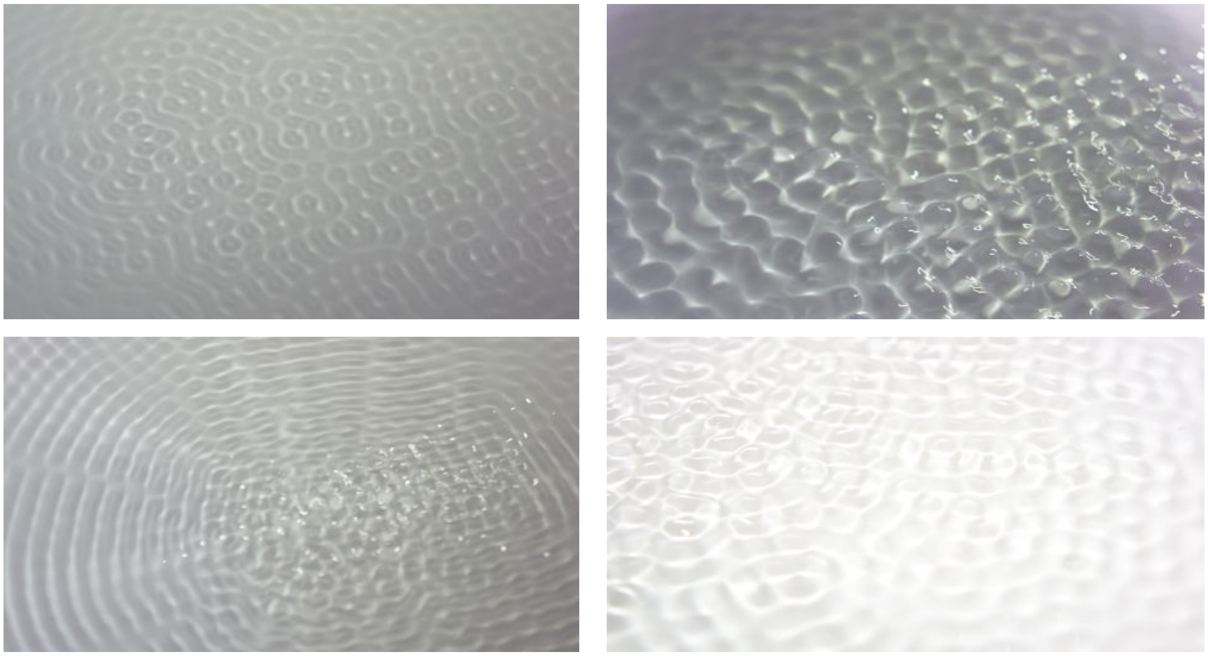

Figure 28: Singular Modulation

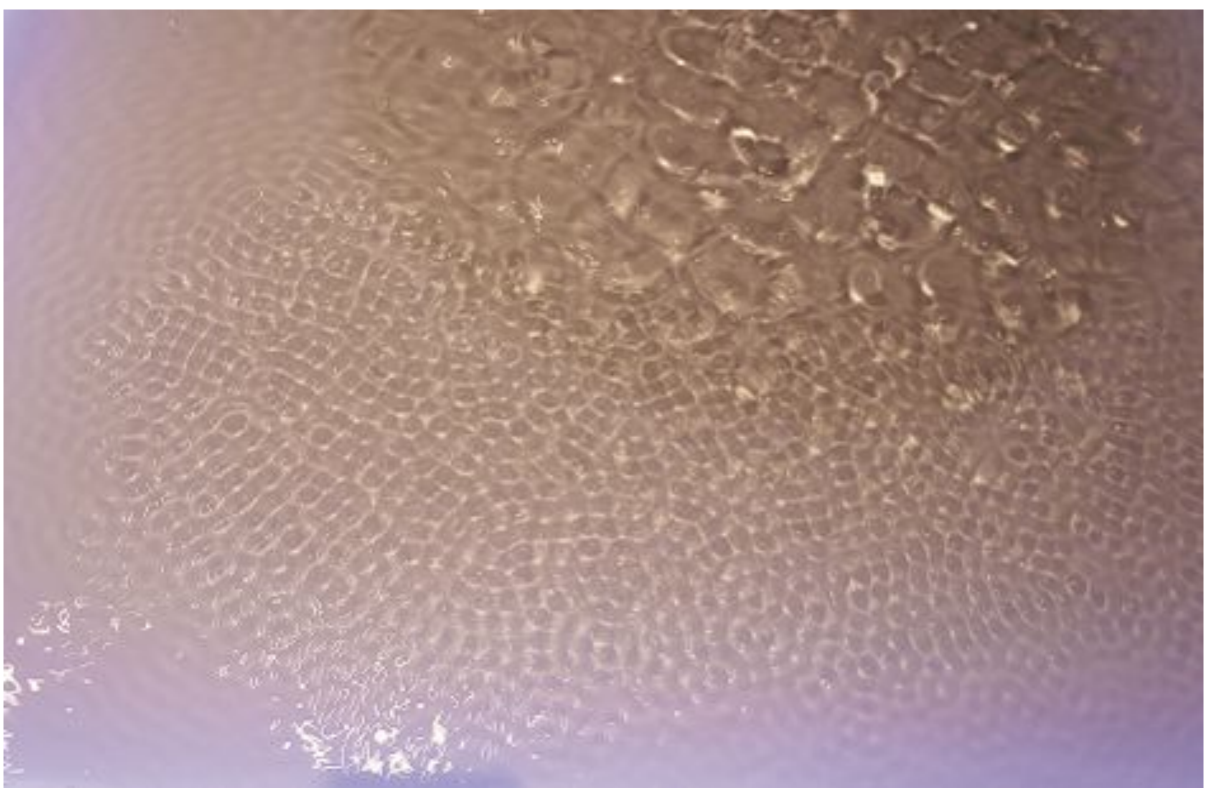

Figure 29: Complex Modulation

Chapter 4

Mechanics of Sound: Cycle

Figure 30: "Cycle" Kinetic Sculpture - CalArts Digital Arts Expo (2015)

"Primary causes are unknown to us; but are subject to simple and constant laws, which may be discovered by observation, the study of them being the object of natural philosophy." - Joseph Fourier

4.1 Project Synopsis

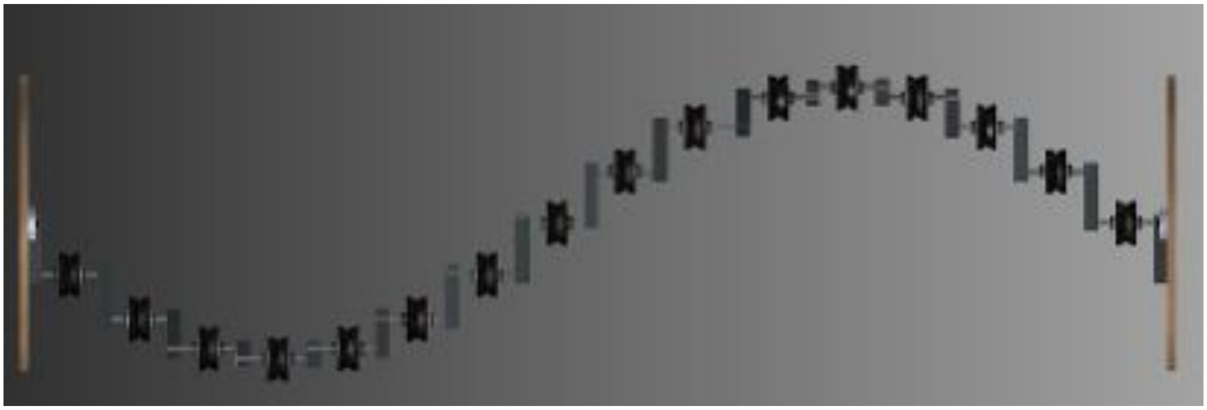

Figure 31: Helix Camshaft Design - Inventor 3D Software

Cycle is a large-scale kinetic sculpture made up of 16 – 2 ft. white aluminum tubes. Each tube is suspended in the air by 12 feet of aircraft cable connected to pulleys. The aluminum tubes are driven by a 10′ x 24″ custom-designed and fabricated steel helix camshaft. The camshaft is attached to a variable ac motor, which is mounted to the top a large steel rack, which supports the camshaft. The entire work weighs over 350 pounds, and is suspended in the air by 1/2" aircraft cable, connected in four corners by hooks on chain motors. When powered, the aluminum tubes slowly rotate in a circular/sinusoidal motion, creating a visual representation of one complete cycle of a sine wave.

4.2 Project Concept

This work attempts to visually interpret and represent the physical characteristics of a mechanical waveform in terms of phase, amplitude, frequency, and wavelength. The mechanical nature of the work, along with the circular motion generated by the helix camshaft, attempt to reinforce sound's intrinsic cyclical nature, allowing the viewer a more accurate depiction of the motion of mechanical waves. From the front of the piece, the tubes flow slowly up and down, creating the appearance of a time-based sine wave. However, as the viewer starts to walk around the piece, they will start to notice that the up and down motion of the tubes is actually circular, producing varying degrees of complex moiré patterns as the tubes cycle and shift. This visual phenomenon continues to shift until the piece is being viewed directly from the side, at which point the tubes reveal what appears to be a 360º circle. Although the work itself does not generate any sound of its own, other than the quiet mechanical sounds of the drive shaft turning, the simplicity and fluid motion being generated by the piece invokes a sense of calmness, similar to the effect of an audible low frequency sine wave. Without any harmonics, the sine wave itself represents sound in its purist and most basic state. The continuous cyclical shape invokes our basic understanding of how various forms of mechanical energy travel, the functionality of alternating current, the ebb and flow of the ocean, the power of a seismic event. Often when viewing sound or sound waves, we are forced into a certain domain, be it in terms of time, or in terms of frequency. These forms of approximation are useful tools for measuring and analyzing a signal. However, the very nature of mechanical, longitudinal waves is fundamentally circular, similar to the push and pull of a slinky. Much like the work NODE, where the patterns of nodes generated create a circular motion, *Cycle* attempts to recreate that same circular motion in the form of a large-scale kinetic sculpture.

Figure 32: Cycle

4.2.1 Chapter Description

In this chapter, I will revisit the various experiments that ultimately led towards the design, build, and installation of *Cycle*. After that, a look into the structural, mechanical and technological requirements to create the work, followed by a discussion regarding possible future work in kinetic art.

4.3 Previous work in Kinetic Art

My very first explorations with kinetic art began from my experience as an undergraduate student at California Institute of the Arts in 2009. During that time, I was a part of a unique course offered between Ajay Kapur (MTIID department) and Michael Darling (Technical Direction department) that focused on the design and fabrication of musical robotics for live performance. Students from both departments collaborated on designing and building various robotic instruments that utilized solenoids, linear actuators, and motors to generate percussive motion. With additional contributions from renowned sound and kinetic artist Trimpin, the class produced a series of percussive robotic instruments that could be controlled using MIDI/OSC protocols.

4.3.1 The Machine Orchestra

Figure 33: The Machine Orchestra - Walt Disney REDCAT (2010)

This interdisciplinary collaboration between Kapur and Darling ultimately led to the creation of *The Machine Orchestra*, a unique hybrid ensemble that combined custom musical interfaces and musical robotics with traditional instruments, dancers, and video projections. The Karmetik Machine Orchestra premiered on January 27th, 2010 at the REDCAT Walt Disney Concert Hall in downtown Los Angeles. (Kapur et al. 2010) My experience as a member of the Machine Orchestra taught me a great deal about the nature of kinetic art through mechanical means. Additionally, it provided a source of inspiration for my future work.

4.4 Initial Experiments

The inspiration for Cycle came out of experimentations involving the creation of *simple machines*. Initially, the goal was to create a series of simple machines that utilized levers, pulleys, wheels, and axles; each device fabricated using the process of CNC routing. The hope was to eventually create a more complex device, but based exclusively on simple motion, and strictly within the limitations of well-documented simple machines. The first machine built involved a pulley system attached to a wheel. A wooden dowel, attached to fishing line, was hung from below the pulley; the fishing line ran through the pulley and connected to the top of a wheel, mounted perpendicular to the pulley at a fixed point. When the wheel was turned, the pulley functioned like a pivot point and the wooden dowel would move up and down, similar to a piston. Watching the circle turn and create a piston-like motion led me to explore the possibility of generating a simple sine wave using the same technique. This initial experiment became the first of three attempts to generate sinusoidal motion with a kinetic system.

Figure 34: First Model - Kinetic 2-Dimensional Sinusoidal Motion

4.4.1 Second Model

The second attempt built on the idea of using multiple pivot points along with a circular crank to generate a simple sine wave out of 12 - 1' dowels. Additionally, the hand crank was replaced with a DC motor. The pivot points, created with eye bolts, were splayed in a diagonal line so that each line of wire had a specific position and could slide back and forth without being effected by another wire. The 12 pivot points on the circular crank were splayed equidistant across the edge of the circle, much like the hours of a clock. This approach highlighted a few areas of concern dealing specifically with creating continuous circular motion with fixed pivot points. For example, after one full rotation of the circular crank, the fishing line connecting the dowels to the wheel would bind up at the pivot points along the crank. After a few adjustments were made with no success, the focus of the project turned to designing a crank shaft that could allow for multiple pivot points to turn freely 360º without binding, and without a breakpoint that could bind the dowels as the lift and fall. Ultimately, this led to the design of a *helical drive camshaft*.

Figure 35: Second Model - Kinetic 2-Dimensional Sinusoidal Motion

4.5 Designing the Helix Camshaft

Designing a helix-shaped camshaft presented a possible solution to the binding problem because the helical shape can be used to produce sinusoidal motion, with the advantage of no connective points to bind or hinder the rotation of a wire hanging from a fixed point. Ultimately, the solution was to design a helical camshaft that utilized pulleys at equally spaced intervals. The dowels would then be fixed to the pulleys, and as the camshaft rotated, the pulleys would rotate counter-clockwise, always keeping the dowels straight. The primary issue with this design was how to maintain the structural integrity of the camshaft without a center support shaft running through the middle of the helix, keeping it from sagging in the center, or springing together like an accordion.

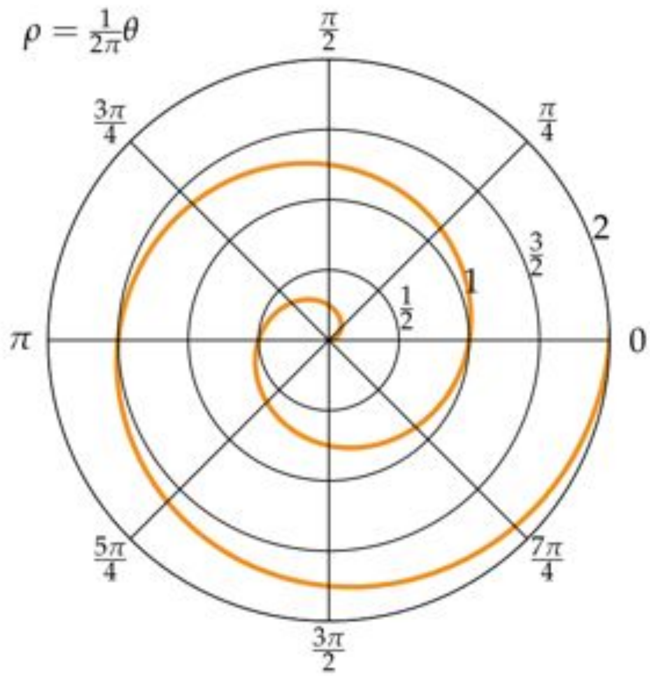

Figure 36: The Helical Design

4.6 Third Model (Helix Camshaft + Aluminum)

The third model of *Cycle* was much larger and involved an upgrade from wood to aluminum 1" box tube for the structural integrity of the camshaft along with the introduction of pulleys, 1 1/2" steel tubes to replace the wooden dowels, and aircraft cable in the place of fishing line to suspend the steel tubes. The new camshaft was first modeled in *AutoCAD* and then imported into *Inventor* 3D modeling software, so the circumference of the helix and every connecting component could be mathematically modeled in 3D and designed exactly to spec. An exact scaled image of the designed camshaft was printed and used as a template for the construction of a jig designed to hold the segments of the camshaft in place, which allowed for proper placement of hardware. The overall size of the third version was much larger than the first two models; the camshaft was designed with a 2' circumference, spanning 8' in length. The entire camshaft was supported on either side by 2' plywood disks, which were attached to a large wooden rack that supported the entire structure. Each end of the camshaft was mounted directly to the plywood disks, which could be turned with a hand crank. The circumference of the camshaft directly corresponded to the amplitude of the steel tubes, with the goal of creating the largest deviation of amplitude as structurally plausible. In order to maintain the shape of the camshaft and keep the shaft itself from bowing, each connecting piece was machined using a series of jigs, allowing for precise replication.

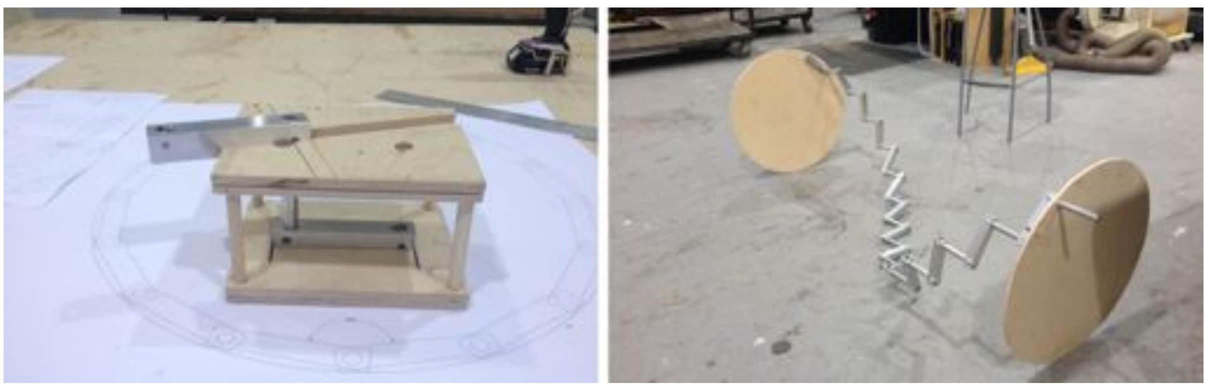

Figure 37: Fabricating the Aluminum Helix Camshaft

4.6.1 Pulleys + Steel Tubes

The addition of pulleys, which were modeled in AutoCAD and cut out of Baltic birch plywood with the CNC router, required an attachment piece of 1/2" aluminum tube in between every segment of the camshaft. The pulleys were attached to the aluminum tube and were center-spaced using a combination of custom-designed aluminum washers and plastic spacers to minimize shifting and excess friction. The use of 1 ½" steel tube for the suspended tubes was chosen primarily because of weight, with the hope of minimizing sway due to the centrifugal force created by the turning of the camshaft. Using aircraft cable to suspend the steel tubes also contributed to minimize any additional swaying motion.

Figure 38: Pulleys & Steel Tubes

4.6.2 An Additional Dimension of Rotation

At this point, the 'sine wave' being generated was still two-dimensional. In order to hold the shape of the sine wave, the aircraft cable for each tube was run through holes drilled into a center support beam made out of 2x4" lumber. This forced all of the tubes into a line, which created a "time-based" sine wave that would cycle when the camshaft was turned. However, after a few hours of turning and tweaking the piece, I started to wonder if I could maintain stability, remove the center support, and introduce an additional 'circular' dimension to the sine wave. There were a few immediate concerns with removing the center support. Because the components of the helix camshaft were being machined by hand, there were minor imperfections that would cause slight shifts in the segments as the shaft was turned. To create a functional two-dimensional sine wave, each component would need to be perfectly fabricated. Otherwise, any discrepancy would be seen in the rotation. The use of the center support beam helped to minimize the impact of these imperfections. Due to personal budget limitations, as well as the desire to fabricate each component without outsourcing the work to a professional machine shop, these slight imperfections would hinder the ability to generate the circular motion of the tubes, causing unwanted sway and bounce. Additionally, the goal for the final piece was to create a much larger work - something that could be suspended and run independently with a motor. In order to create a stable camshaft, it would be necessary to re-enforce the structure with heavier material and weld the individual joints to ensure that no individual component could shift.

Figure 39: Adding a Third Dimension

4.7 Technical Aspects of Cycle

The final version of Cycle consisted of a 10' x 24" welded steel helix camshaft with 16 pulleys, mounted to two 24" CNC-routed plywood wheels. The plywood wheels were mounted to a 3" diameter aluminum tube supported by shaft collars, which, in turn, were mounted to steel plates, attached to a 10' x 4' large welded steel rack. The pulleys, held in place by 1/4" setscrew collars, loaded with ball bearings, allowing for full-range of rotation around 1/2" steel bars, which were side-welded into 1 1/2", hand-machined box tube. Attached to each pulley was 12 feet of aircraft cable, leading down to a 2' aluminum tube. The aluminum tubes were painted white and filled with sand in order to keep them stationary when rotating. A large AC motor, mounted to the top of the steel rack, controlled the entire work. The camshaft was driven from the motor by way of a large chain. Every component of Cycle, with the exception of the motor, the pulleys, and some miscellaneous hardware were hand-machined by the artists.

4.7.1 Fabrication Process

The process of fabricating such a large kinetic work relied heavily on technical drafting, jigging, and precision machining. Each component was drawn up in AutoCAD and then re-designed in Inventor to model in 3D and verify weight tests. Additionally, each segment of the camshaft was fabricated separately, with every step requiring a complex jig. All of the jigging required for each component was drafted and then cut using the CNC router. Once all of the parts of the helix camshaft were machined and assembled, the camshaft was mounted onto a 12' - 3" aluminum tube supported by pillow blocks. From this point, each component of the camshaft was welded together, held in place by additional jigging that maintained the exact position of every pulley. Once the pieces were welded and the angles of each segment were verified, the jigs were removed and the camshaft was tested. At this time, the steel rack was cut and welded, and the camshaft was installed into the rack, attached by plate steel and shaft collars. Finally, the aluminum tube that supported the camshaft was cut and removed, leaving only the ends to allow the wheels to turn in the shaft collars.

Figure 40: The Helix Camshaft with Jigs & Steel Rack

4.8 Installation of Cycle

Figure 41: Installation of Cycle

Due to the size of the piece, the final components had to be assembled after Cycle was installed. Once the camshaft/rack were properly attached onto the chain drives, the rack was lifted up 4 feet and the motor plates, motor, and drive chain was attached. Once the motor was tested, the aluminum tubes were filled with sand and attached to the pulleys via aircraft cable. In order to attach the cable to the tubes, custom plug housings were designed, CNC routed and installed inside the tops and bottoms of each tube. The top plug had additional hardware that clamped the aircraft cable directly in the center of each tube. Once the tubes were attached, the camshaft was powered on and, for the first time, *Cycle* was fully functional. Work on *Cycle* began on October 2nd, 2014 and was completed on May 4th, 2015. The piece installed in the MOD Theatre during the CalArts Digital Arts Expo a few days later, and ran for a mere 9 hours. The piece was initially rigged to be suspended 20 feet about the gallery floor, but was later lowered closer to eye-level, in order to allow viewers a clear view of all sides of the work.

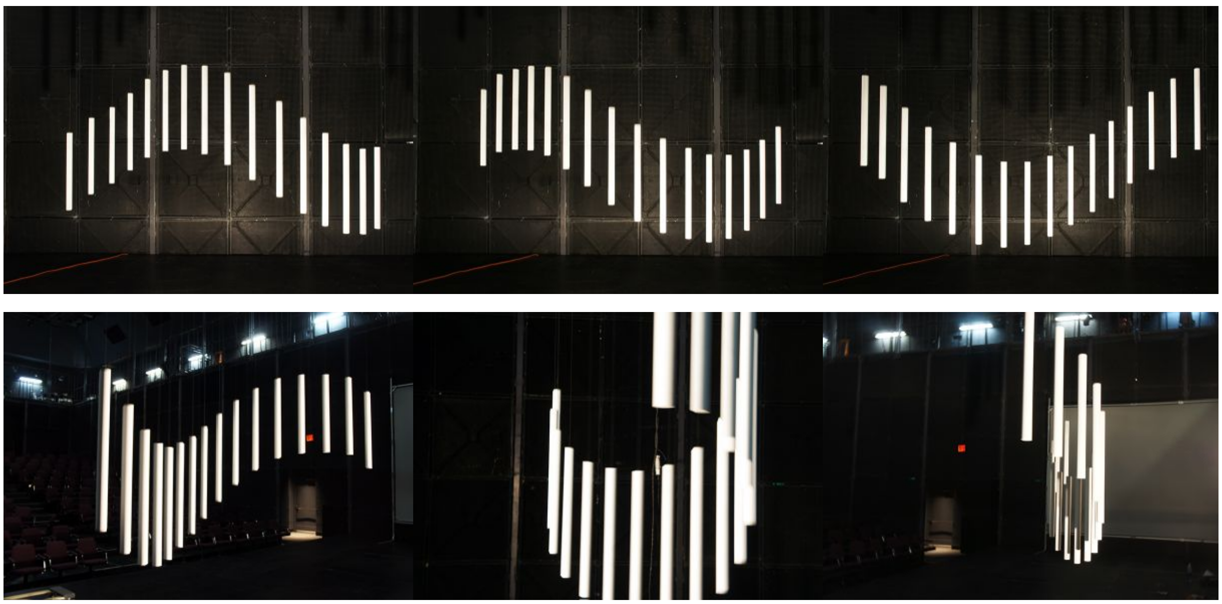

Figure 42: Cycle Rotation - Various Angles

4.9 Future Work in Kinetic Art

Based on my experience with this project, I have considered many possible variations of the work. One such possibility would be exploring ways to generate variations in amplitude of the tubes, without the use of any linear actuators or motors. It might also be interesting to add a sonic and interactive component to the piece, where a room's amplitude might directly reflect the amplitude of the kinetic sculpture.

Chapter 5

Tangible Sound: Phase (Series)

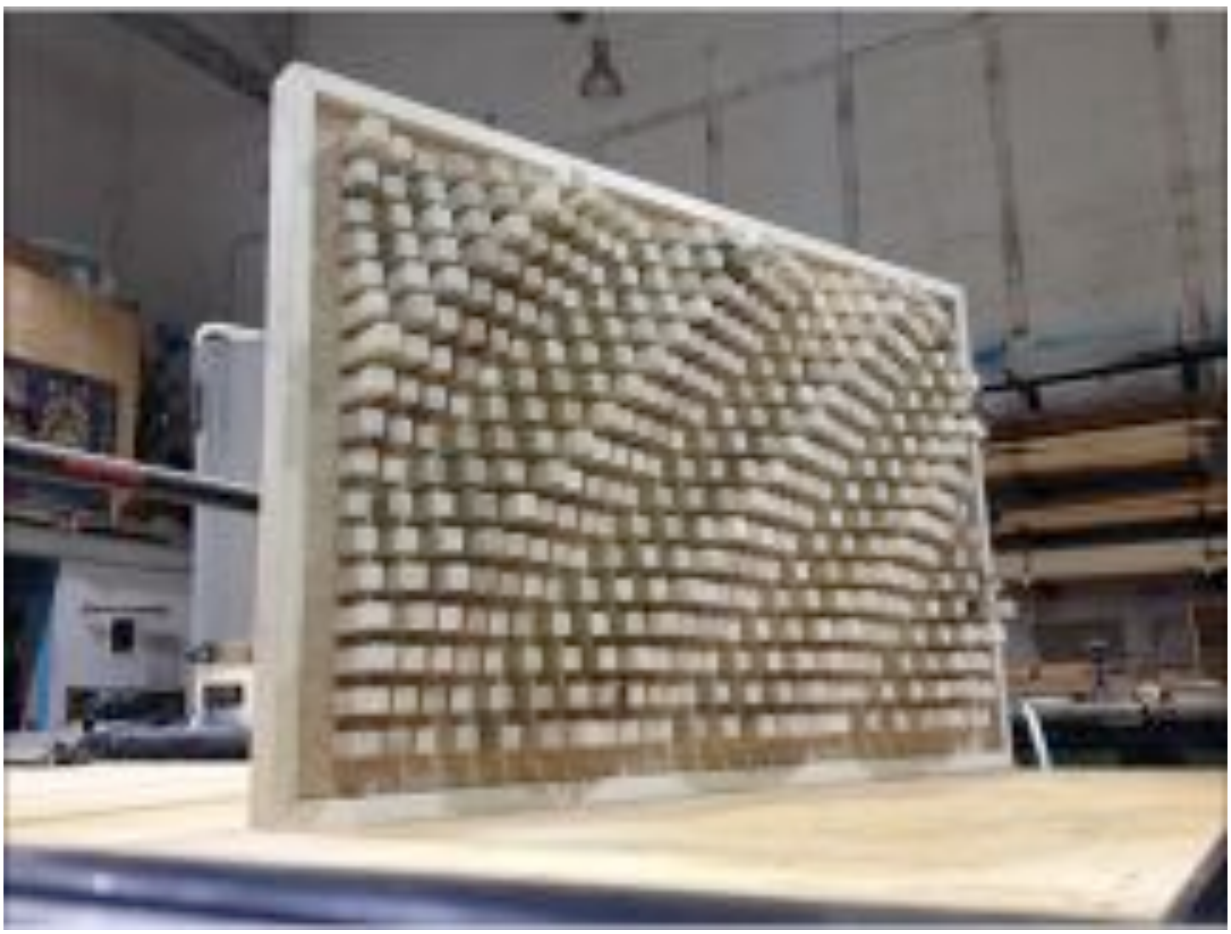

Figure 43: Phase #1 (2015)

"Sound is a property of the physical world - the vibration of air; and you have to know the characteristic of that sound itself. So physics is that part, and mathematics is very much the composition." - Ryoji Ikeda

5.1 Project Synopsis

Phase (Series) is an ongoing series of *topographical* sculptures depicting information we cannot see - the complex harmonic relationships of sound - by creating an augmented physical sound/data imprint of various sonic phenomena. Topographic Art is essentially art depicting places, buildings, and natural prospects in a realistic and detailed manner.[37] This work attempts to focus on a specific moment in time, capturing the sonic information of a single instant - the change in dynamics of a specific set of harmonics - and visualize those relationships within the framework of a massive array of wooden dowels. These sculptures are meant to function much like a three-dimensional snapshot of sonic behavior, utilizing methods of feature extraction to measure, condition, and re-interpret streams of sonic data, converting the unseen world of sound into a physical, tangible structure. This approach, which I call *Sonic Topography,* gives the viewer a unique perspective of sound in a way that is visually stationary - a physical manifestation of a sort of *harmonic fingerprint* - one that can be closely examined, experienced, and understood without the need, necessarily, for the aural reproduction of the sound itself *(although attempts to include an audio reference will be discussed in this chapter).* Much like a topographical map shows the geological contour of a specified terrain, these works attempt to show the complex envelopes of sound in a way that is similar to an FFT waterfall plot, but in a physical sense.

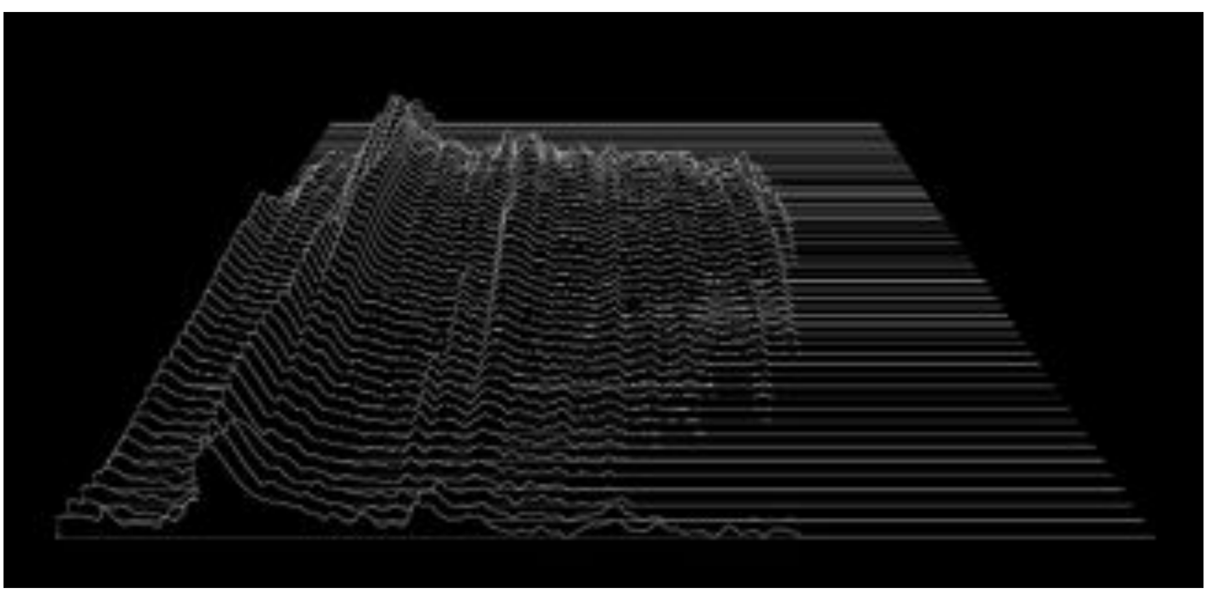

Figure 44: FFT Waterfall Plot of Sonic Material

[37] http://weburbanist.com/2012/02/20/lay-of-the-land-13-topographic-works-of-art-design/

5.1.1 Phase #1

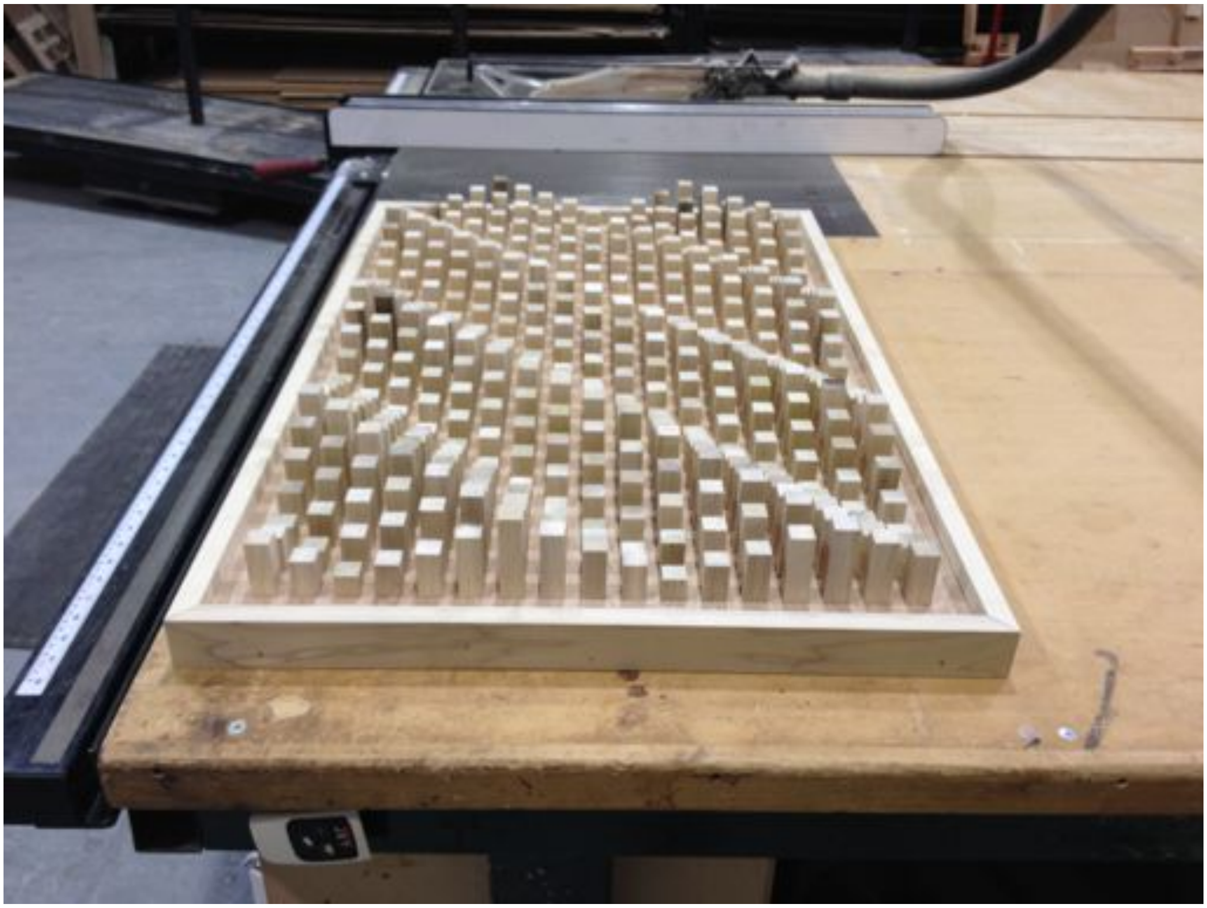

Figure 45: Phase #1

The first work, *Phase #1,* is a 2'x4' sculpture made from apple plywood and seventeen rows of poplar dowels. This work represents the shifting phase relationships between multiple sine waves, with each row offset from the previous in series. A secondary sine wave is also present that is created from the offset patterns of each row as the dowels rise and fall across the piece. This 3D ripple could be considered a segment of a sound wave as it propagates through a medium. The plywood back of Phase #1 was digitally fabricated using a CNC router to create 459 equally spaced indentions (pixels) to mark where the dowels would go, and to hold them in place. Each dowel was then individually cut to a set size using a miter saw, glued, hammered in to the pixels, and leveled. The use of pixels to determine dowel position gives the work a "digital" representation of a waveform by referencing how digital systems sample contiguous signal, with the number of dowels dictating the accuracy of replication.

Figure 46: Phase #1 - Fabrication Process

5.1.2 Phase #2 (Spectrum)

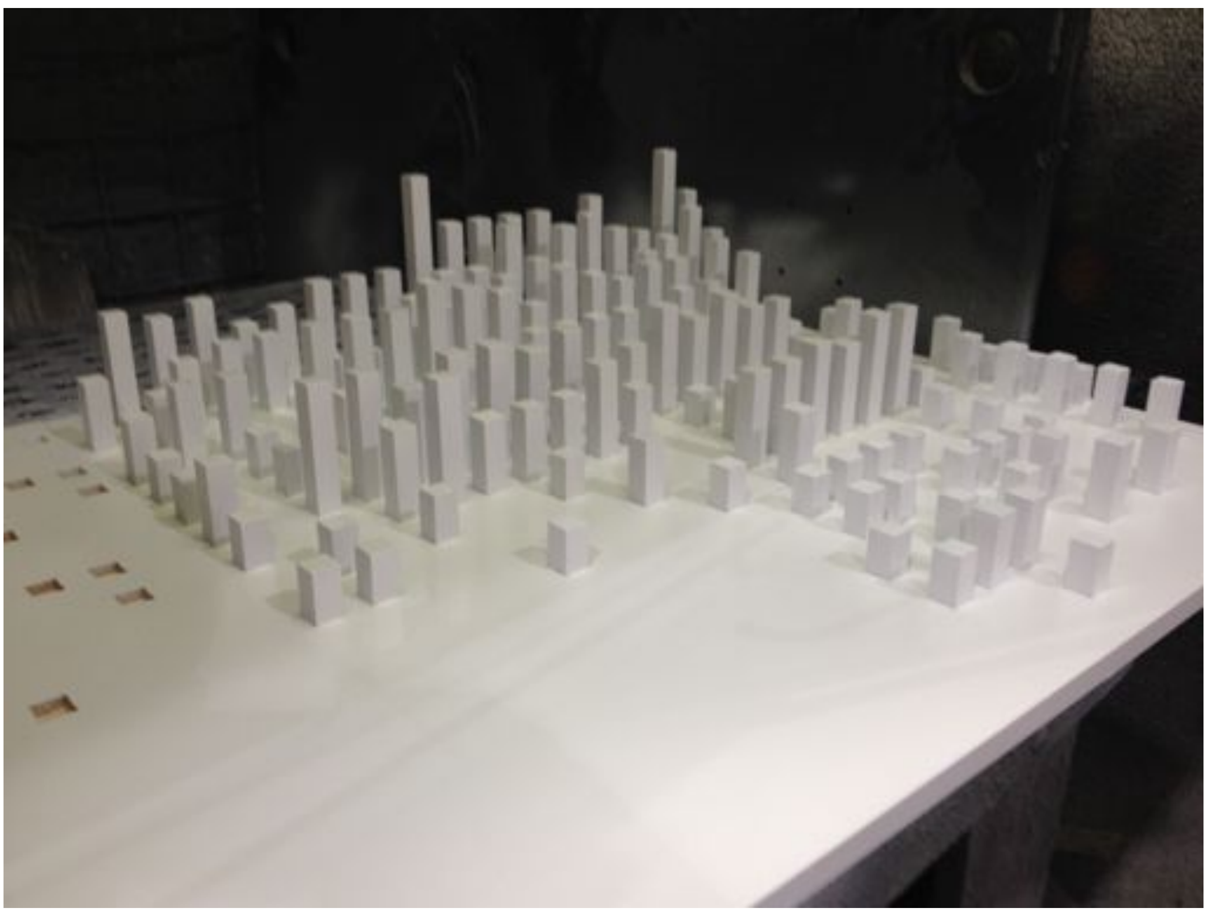

Figure 47: Phase #2 (Spectrum)

The second work, *Phase #2: Spectrum,* is a much more ambitious and complex sculpture that focuses on the harmonic spectra of an actual piece of audio. In order to accomplish this work, harmonic analysis tools were creating in the ChucK[38] programming environment that could analyze an audio file spectrally, and output the magnitudes of the various frequencies to a table in Excel. Additionally, the FFT data is sent to Processing[39] via Open Sound Control (OSC), where a basic visual representation of the sculpture is generated and can be referenced in real-time. Once the spectral data is extracted from the audio and stored into a table, the amplitude values of each harmonic are converted to inches, which dictates the length of each dowel in the sculpture. In addition to dowel length, the data is also converted into "pixel" data using AutoCAD, with a small square rendered for every harmonic in the data set. This allowed for blank space on the sculpture panel where there was no harmonic information.

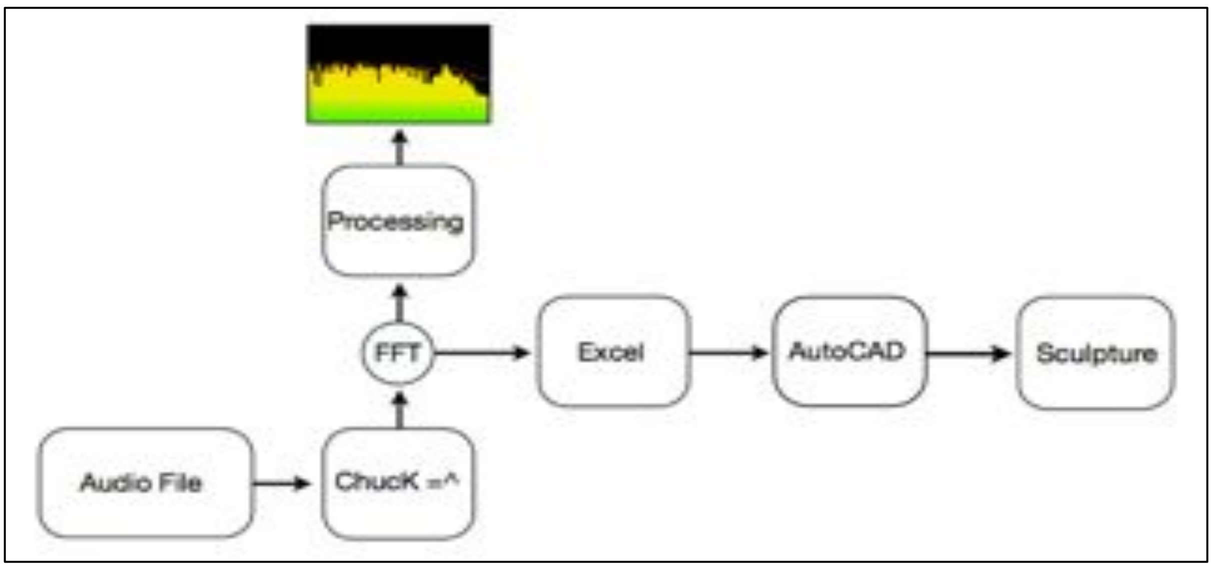

Figure 48: Digital Signal Flow - From Audio to Sculpture

5.1.3 Truncated Data

This 16 ft. long topographic sculpture was broken down into 8 -2' segments which were individually CNC routed with nodes to mark wherever there was harmonic information. The FFT data used to generate these nodes were limited to 16 bands, and the sample rate was truncated and averaged during analysis in order to fit the spectral information on the piece.

[38] http://chuck.cs.princeton.edu

[39] http://www.processing.org

Each of the 2500 dowels used to recreate the spectral information of the musical piece represent a harmonic moment in time, and was individually cut with size dictated by relative magnitude of the specific harmonic. The 8-apple plywood panels were then mounted to welded 1" steel box tube for mounting purposes.

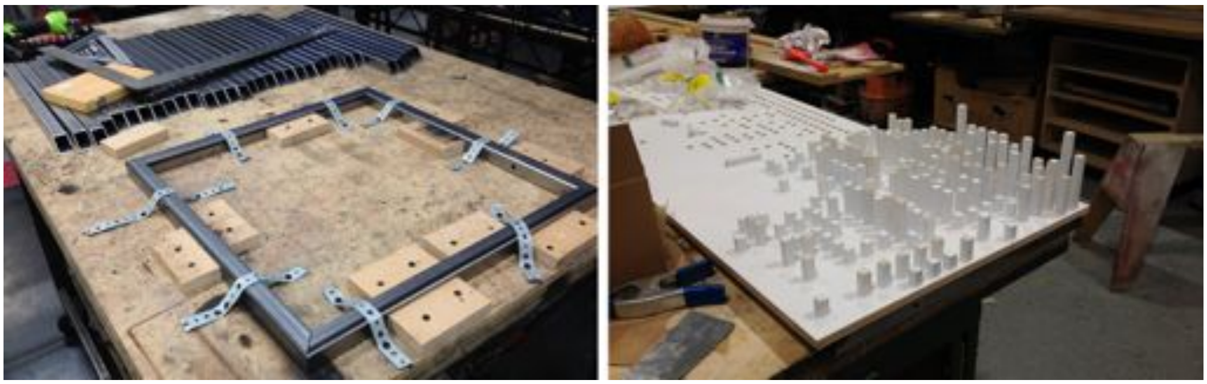

Figure 49: Mounting Frames & Dowels

5.2 Future Work

This series of sculptures is an ongoing project meant to explore various approaches to sonic topography. The work Phase #1 was completed in the fall of 2014. Phase #2 (Spectrum) is currently a work-in-progress, with the current goal of creating a series exhibition for the spring of 2017. Phase #2 (Spectrum) is meant to serve as an augmented sound data sculpture representing a piece of music. Since starting this project, there have been various possible technological additions that are currently under consideration. The first addition would be to add a sound component to the work, embedding hidden speakers behind the panels in order to play the original audio that was used to create the piece. A second component under consideration is the addition of a sensor or camera tracking system that would track the movement of a person viewing the sculpture. The position of the viewer in front of the sculpture would then dictate the play position of the audio, allowing the viewer to "scrub" the audio as they traverse the sculpture. This would give the viewer a clear audio reference of the frequency content modeled on the sculpture, and allow them to control the direction and speed of playback based on their relative position to the piece.

Chapter 6

Conclusion

6.1 Summary

This document presents a section of work created by James Meason Wiley during his time as an MFA student at California Institute of the Arts. The projects included in this thesis represent the author's desire to create work inspired by the natural world around us – through both direct and indirect means. The work presented in this document specifically references various approaches to visualizing sound through interactive art, kinetic art, and topographic sculpture, utilizing various digital and traditional fabrication techniques. Additionally, this work highlights methods for sound visualization, as well as natural systems in general, through three primary themes: *movement, structure,* and *connectivity*. This thesis represents a starting focal point for the author in terms of generating work – one that will continue to be explored for many years to come. As we advance into the 21st century, technology will continue to play an increasingly large role in our lives, connecting people across the planet, creating new opportunities for the advancement of our species, and continually shifting the paradigm of what it means to be human. In the face of this advancing technological world, it is imperative that we not lose our sense of connection with nature.

In terms of art, my goal is to create work that amplifies our fundamental connection with nature and natural systems, and to highlight the beauty of these structures – both visible and beyond our perception. As humans, we are often mesmerized by what we cannot see, hear, or touch. Creating work that seeks to augment the imperceptible, or overlooked components of our environment has become one of my primary focuses as an artist.

6.2 Primary Contributions

6.3 Final Thoughts

This thesis highlights the author's desire to create an artistic framework for examining the beauty and complexity of natural systems. The work presented in this document is also meant to highlight the similarities between our man-made environment and what occurs fundamentally in nature, whether these similarities exist as the result of architectural form, utilitarian design, or a function of society in general. No matter how separate from nature we may feel, humans are aesthetically linked to our natural world. Within the field of Biomimetics, we are constantly finding ways of improving man-made objects by modeling natural systems. (Ruys 2013) To approach art in similar terms is to provide a context for a deeper sense of connection between humans and their natural surroundings.

6.4 Future Work

In addition to the continued exploration into the various topics covered in this thesis, I have recently started work on a new series of digitally fabricated sculptures focused on the concept of the moiré effect. My first attempt at moiré sculpture will be presented at NMASS in June of 2016. I have also started work on a sound art piece, "Fractals", that utilizes large blocks of ice, embedded with hydrophones. The hydrophones pick up the sound of the ice slowly melting, relaying the audio into custom software that processes and amplifies the signal. The processed audio is then fed to a series of speakers mounted around the ice block. The ice block itself sits on a large light table, which highlights the emerging fractal patterns in the ice as it melts. I hope to complete and install this work sometime within the next year.

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