California Institute of the Arts

Biofeedback Apparatuses For Exploring the Intersection of Scientific and Artistic Views of reality.

by

Martín Vélez Mora

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Supervisory Committee

Owen Vallis

Mentor

Ajay Kapur

Committee Member

David Rosenboom

Committee Member

Colin Honigman

Committee Member

"It's one thing to question your mind. It's another to question your eyes and ears. But then again, isn't it all the same? Are senses just mediocre inputs for our brain? Sure, we rely on them, trust they accurately portrait the real world around us. But what if the haunting truth is they can't. That what we perceive isn't the real world at all, but just our mind's best guess. That all we really have is a distorted reality, a fuzzy picture we will never truly make out."

Mr Robot.

Abstract

Science and art present two views of reality, this thesis is interested in where these two views intersect, and explores the intersection through the development and use of biofeedback systems. This work aims to create connections between artistic statements and physical manifestations, and balance the weight attributed to art and science giving them equal importance, but more important, highlighting a reciprocal behavior between them, particularly for music, sound and sonic art.

Following that idea, this thesis discusses the relationship between contemporary science and contemporary art, how they are different as well as what links them together. On the one hand, there is the scientific idea that there is a discoverable reality waiting to be revealed, independent from the observer's state of mind. On the other hand, there is the more abstract idea that reality is partly a construction of the human mind, linguistically and phenomenologically determined, and therefore unfixed. These two views of reality have been discussed throughout history and are embodied in Platonic reason and Aristotelian empiricism.

The synthesis of these two points of view creates what we perceive as reality. This perceived reality is mediated through our mind, body, and environment. Our body and environment become then the canvas where the latent synthesis of reality happens. Modern technologies allow us to retrieve bio-signals, such as EEG and EKG, which allow us to leverage and use the human perceptual apparatus as a control source for creative work. This system processes inputs, in the form of stimulus (music, light, movement), creating a feedback loop between the performer and the interface. This process is known as biofeedback, and has been used for many years by both the scientific community and artists. These systems allow a performer's latent synthesis of reality to influence their control over the system.

These ideas will be used to build a musical system based on two instruments that detect EEG and EKG signals respectively. This system will reflect the exploration of the Platonic view of reality through an Aristotelian approach. The projects and research presented in this thesis aim to give a solid structure and connection between both views of reality. Examples of science

influencing art or art influencing science will be presented as well as reflections of what constitutes "human nature," or in this case human imagination. The main objective of this work is to create new works that not only stimulate our physical senses, but also awakens questions inside us about our daily construction of reality.

Acknowledgments

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Introduction

"It's the artist's ancient role to communicate between a timeless other world and the physical world of the here and now, capturing the moment in order to evoke a response which derives from imagining the living scene and understanding its essential, eternal significance. Art halts time and defies death"

--Leonard Shlain (2007)

Nowadays there exist two main theories that support both the Aristotelian and the Platonic views of reality. First there is the idea that reality is a process of experience and interaction with our environment thus revealing a more biological approach, whereas on the other side there exist the idea that what is real is predefined, immutable and constant, revealing a more abstract way of thinking. Both of these theories have their supporters and detractors as well. As Leonard Shlain says in his book *Art & Physics* "Art generally anticipates scientific revisions of reality. Even after these revisions have been expressed in scholarly physics journals, artists continue to create images that are consonant with theses insights."[1]. In his book, his thesis states that art has somehow inspired scientific minds to investigate topics that they would not have thought of without the art. He refers to arts as a tool to discover reality and the physical world through interaction with it, thus supporting Aristotelian ideas that the objects or forms perceived are only simple characteristics of concepts we had arrived at through actual experience.

On the other side of the spectrum, there are some people who think that the object perceived and the act of perception are linked and therefore independent from the observer's point of view. Indeed, these more Platonic points of view, were influenced by mathematical ideas such as the existence of a universal constant, which becomes a clear indication that reality is eternal,

immutable and only partly accessible to human perception. Most people believed this point of view for the last century where the division between art and science was more evident than ever, giving science a powerful place as seeker of truth while art was seen as a more ephemeral and emotional connection to existence

Another dividing line that seems to exist between art and science is their purpose, or the intention. Art seems to have a non-utilitarian purpose; art is sufficient unto itself. Science's driving motivation, on the other side, is to empirically describe our reality and these descriptions provide then solutions for everyday life. Art is a means of highlighting local or global daily issues, but does not necessarily provides an answer to them and not all artists are interested in making them evident.

Currently, the dividing line between art and science is being slowly dissipated by modern scientist artists and artist scientists. Siân Ede highlights this in his book *Art & Science* when he states that, "contemporary scientist often talk about beauty and elegance, they create visual images, models and scenarios, they have insights into the workings of our bodies and minds which challenge the way we construct our identities and selves."[2]. Science, like art, is a human construction; both are ways that humanity has found to express the world around us after thousands of years of evolution of human intelligence. One does not necessarily come first then the other; they evolved together along with human cognition and are a reflection of a culture's state of mind at a specific period in time. It seems then that there is space to explore the duality that exist in these fields in order to achieve a better understanding of how we use these two tools that we created for interacting with reality (Figure 1).

In order to explore the interaction existing between these fields, we need to retrieve information at their point of intersection which is the human body. The process for retrieving this information is known as biofeedback. Biofeedback is the process of electronically monitoring a normal automatic bodily function in order to train someone to acquire voluntary control of that function. Signals such as heart rate or brain wave activity can be measured through this system. Artists throughout history have used this technique in different ways and relied on different mediums to express the biofeedback output. This thesis will use sound as the primary medium for leveraging the biofeedback data.

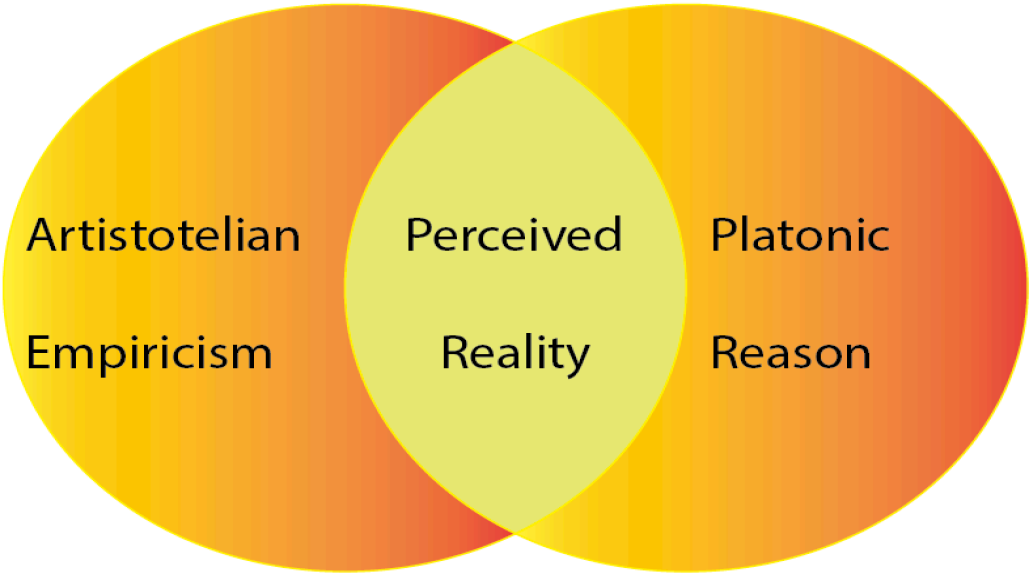

Figure 1. Perceived reality

The word music comes from the Greek word *muse*, for deities that inspire the human mind to express themselves through arts, particularly music and poetry. Music was one of Pythagoras' obsessions, and he found in it evidence of the inner symmetry and elegance of the universe. Indeed, he found that numerical ratios underlie the aesthetic experience that constitutes musical harmony, and many of those ratios and proportions are still embedded in western music, e.g., western modes such as Lydian and Phrygian and musical forms such as sonatas and symphonies. This segmentation of the musical experience into numerical ratios evidences the scientific approach that composers and music theorists have been developing and embedding into musical tradition for centuries. The connection between music and science is even more evident in contemporary pre-compositional approaches to music such as dodecaphonic or serial music. This places music in a good position to become the medium of interaction between art and science for this thesis.

However, if we only rely on music for the exploration of reality then we are neglecting the other human senses such as sight, smell or touch. In order to explore how our other senses, create our reality we need to provide stimuli to them as well, such as visual content and direct environment affection. To address this issue, contemporary techniques such as virtual reality and augmented reality will be implemented in order to see if they can be seen as modern biofeedback

techniques, in the sense that they take a physical sensorial input and use it to transform either real or virtual reality into something new. This raises the question, is the pure extraction of vital signs considered biofeedback even if it is not being fed back into the system itself?

1.1 Biofeedback

Human brainwaves were first measured in the middle of the 1920's by Hans Berger. The first applications were in the medical field, specifically for diagnosis of epilepsy and other neurological disorders.[3] With the use of electrodes attached to the human body it is possible to measure and monitor the current biological state of the person thus revealing a more Aristotelian approach to the present, a more empirical one since the results reflect an immediate reaction to the surroundings. In music, electroencephalogram (EEG) biofeedback has been used for many decades now, with Alvin Lucier being the first composer to retrieve and amplify brain waves for compositional methods in his 1965-piece *Music for Solo Performer*.[4] Other composers such as David Rosenboom and Richard Teitelbaum, have since continued the compositional method of retrieving brain waves for use in their music. As far as electrocardiogram (EKG) biofeedback is concerned, its applications into art are not widely used. As a medical tool, it is used to detect the heartbeat and measure blood pressure in the body. These two parameters are very close related to the physical activity of the subject and can be used in an interesting compositional way. This particular biofeedback (EKG) interests me personally because I have had two heart surgeries, the first, when I was born, so I have spent my entire life monitoring my heart signals through different EKG systems. It has always amazed me how technology allows us to see and listen in real time to the heart's behavior. Also, all the sounds that are inherent with that process always seemed like a song to me, probably because of the periodicity of the heart, giving the sensation of a musical beat.

1.2 Aims/Objectives

The projects presented in this thesis explore and come to a conclusion about how art and science cooperate to create the perception of the real world that we live in. Across the thesis, each chapter will describe an ambivalence between two opposite concepts which through the exploration of each one, it will create balance between them. Chapter 2 introduces the historical background of art and science as an exploration for describing reality starting from the Geek era,

then goes over the scientific method developed by Descartes and Bacon in the seventeenth century. Approaches of art and science in collaboration that are more modern, are evidenced in music, such as the ones made by Pierre Schaeffer with his reflection about sound objects, and Iannis Xenaki's multimedia approach to art. Furthermore, modern artists that I find inspirational such as Stelarc, Neil Harbisson and Marina Abramoviç will be presented as the root of the artistic statement for this thesis.

Chapter 3 explores the use of scientific technologies taken from the laboratory and used for sonic expression. Using devices originally created in a scientific environment such as an EEG or EKG detector allow for exploration of how the body reacts in different circumstances and manipulates the signals emitted by the subject. The main goal is to create a cyborg system where the bio-signals of the user are used as source signals for control of musical parameters. The system then delivers an audiovisual stimulus that is recaptured by the user which re-triggers new bio-signal responses. This creates a feedback loop between the music, the environment, and the user.

This system reflects the idea that external stimulus influences us since our conception and in conjunction with our cognitive process inside our brains; we create the reality that surrounds us including arts and science (as seen in Figure 2).

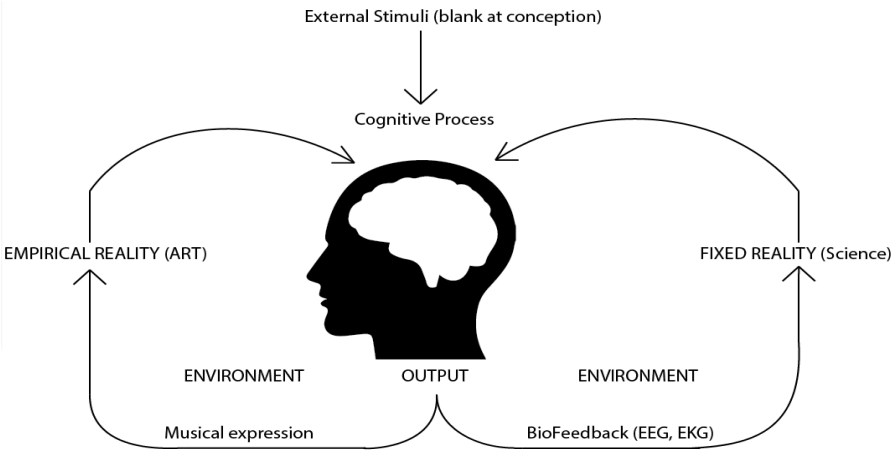

Figure 2. Biofeedback Reality

Error! Reference source not found. explores the interaction with sensors that detect our environment and how it can lead to two different systems of virtual and augmented reality. The first one consists in the creation and development of virtual reality web based applications

designed for the Google Cardboard® viewer using JavaScript. The second one consists of an augmented reality ping-pong table installation, that, through the use of multi modal sensors systems, detects the user's movement and interaction with the table and the space, then processes those signals to deliver a modified, augmented reality. The use of different multimodal sensor systems such as Arduino, Raspberry Pi, Blue Bean, are going to be explored through this project. All these technologies are open source hardware and software for custom electronics that can be reused in any way and will allow cheap reproduction in case these projects are used in large scale scenarios like a ping-pong orchestra.

Chapter 5 is a conjecture about the influence art has had over science. Starting from how pre-Renaissance and Renaissance artists gave new perspectives to a two-dimensional world and set up the base for revolutionary ideas in physics such as inertia. Great artist-scientists such as Leonardo Da Vinci, Salvador Dalí, and Einstein, amongst others, will serve as examples of people who were able to conceive imaginary realities that were later proven to be possible interpretations of reality.

Finally, Chapter 6 presents the results of all the projects and reflections presented in this thesis. On one hand there are all the physical and tangible outcomes of this thesis, such as the EKG and EEG interfaces, the virtual reality ping pong table, and all the code developed and implemented for achieving these goals. On the other hand, there is the artistic and social statement that I have made. I am interested in seeing how this integration of art and science can lead to a more cohesive expression of my art and myself as a musician and artist, but also in how this integration can reach more people and help furthering the dissolution of the dividing line that was created between art and science.

Chapter 2

Historical Background

This chapter provides a selective overview of historical, theoretical, and technological approaches that have been undertaken throughout history for explaining the two main concepts of the thesis, what is "art" and what is "science"? In addition, how different artists and scientists have approached them throughout history. First, we'll look deeply at the Greek origins of these philosophies, embedded in Aristotelian empiricism and Platonic reason, that set up the bases for approaching these two disciplines throughout history. Next, this chapter will discuss the rebirth and further development of this Greek heritage carried out in the Renaissance, examining the birth of the scientific method with Descartes and Bacon and how it has been implemented as an infallible method for research in contemporary science.

Later on, this chapter will look at what is the state of the art of the last century in order to put a chronologically close and solid base for the following ideas that are presented by the projects exposed in chapter 3 and 4. The starting point for this contemporary overview of the arts consists on conjectures about the future of sound-noises with Russolo's *"The Art of Noises: Futuristic Manifesto"*[5], followed by a neurophenomenological approach to how we listen as concieved by Pierre Schaeffer that derives in the creation of music Concrète. Finally, the work of contemporary artists Iannis Xenakis, Stelarc, Marina Abramovic, and Neil Harbisson, will be examined in the context of art and science and its influence over the original work presented in this thesis.

To conclude, this chapter will introduce the biofeedback technique as the focal point for all research presented in this thesis. Biofeedback allows the retrieval of latent information from an

organism, revealing the current state of different biological processes inside the organism's body. It is the tool for measuring our constant interaction with reality.

2.1 Greek heritage

In his seventh book of *"The Republic,"*[6] Plato introduces the myth of the caveman that deals with human beings' relationship with knowledge. With it, Plato tries to introduce the concept of two worlds or two types of knowledge. First is the reality that we experience through our senses. The second is the world of ideas which we access through reason. In the myth, there is a group of prisoners who were born in a cave and the only thing they see are shadows that are casted on the wall by the external light, and the only sound they know, comes from people talking outside the cave that they hear from far away. Then one of the prisoners is released and gets to see all the wonders of the world. After that, he returns to the cave where the other prisoners are still held and tells them about the external world. The prisoners did not believe any of his tales, took him for a fool, and threatened to kill him if he ever tried to release them.

The point of the allegory is that we as humans are prisoners in a world of appearances (shadows) that we interact with through our senses. The external and wonderful world represent the world of ideas that the philosopher is trying to access and to guide the other human beings towards that. The threatening towards the philosopher represent the pain and rough path that people who wants to access the world of ideas have to go through in order to reach illumination.
In this rhetorical statement, Plato reveals his idea of a reachable reality that is out there and that is accessible for those who seek for it. In other words, he states that there is a tangible unmodified reality that is reachable for those who look for it. On the other hand, he also acknowledges the existence of another more empirical reality that we perceive through our senses.

Figure 3. Plato's cave myth

It is here where Aristotelian and Platonic views conflict because for Plato the world of ideas is reached through reason. Aristotle was Plato's apprentice but he had his own way of thinking and criticized his maestro and his ideas. Even if Aristotle admits the existence of the world of ideas he thinks that it is not only reachable through reason but through experience, the empirical approach. For him, the world of ideas is not separated from the world of senses, meaning that he does not believe in a universal truth that immutable and true in and of itself. It is only through experience and the evidence of the senses that knowledge is constructed. Aristotle does not conceive that the cause of a thing is not included in the thing itself. How can it be that whatever is that makes a human an individual is not embedded inside that person himself?

At this point Aristotle realized that we must make a distinction between what the senses contribute and what our minds interpret. There exist then a grey area where reality and fiction live together, we don't realize that we are in a dream until we wake up from it. This intersection is reflected in the way that art and science approach reality, because they have been used as tools for unveiling what's real and what's fantasy. This is why, for the biofeedback system that is implemented in this work, it needs to be tested and performed by the same subject because the conditions of the system are different for every subject, making this a very personal and individual system.

2.2 The scientific method

René Descartes was a French philosopher and mathematician from the 17th century, who was influenced by the reignited interest of the Greek era philosophers that occurred during the 16th century by renaissance artist-scientists such as Leonardo da Vinci. Indeed, Descartes was dissatisfied by how science was still treated in a medieval way because it was based on authorities from the past rather than in observations of the present. In his book *"Discours de la Méthode,"*[7] he states his ideal approach on how to interact in a scientific way with the world that surrounds us. He established a set of rules that would reveal an a priori approach to the real world. Like Plato, he thought that, the same way as mathematics and geometry, reality has pre-established rules or self-evident truths that can be demonstrated through equations. "Those laws of reality imply an a priori method to discover infallible knowledge, a method that it is linked to Plato's world of ideas, that carries an intellectual knowledge of the essences of the things with which we are familiarized in our sensible experience of the world"[7]. This also reveals the influence of his mathematics background in the way that he structures a more logical thinking and tries to find perfection within nature and science. This is the scientific approach that has ruled the scientific field ever since, and by applying it, significant irrefutable discoveries have been made. Discoveries such as humans having different types of blood or that infections, viruses and bacteria are the cause of diseases and plagues and therefore sanitizing and sterilizing exist.

At that same moment, on the other side of the spectrum, other thinkers developed a more empirical approach to reality that follows the path of Aristotelian empiricism. People like Isaac Newton or Francis Bacon did not believe in the metaphysics of essences and the paradigm of innate ideas. For them the real knowledge of the world of senses has to be located, not by going outside of the realm of essences, but by applying the experimental method of causes and effects in order to detect emerging patterns that can be then quantified. Revolutionary theories such as gravitational laws are based on mere deductions or analysis of environmental behavior but are standing upon abstract perceptions of reality.

These two points of view however, have a lot in common. They claim the complete overthrow of all the methods and most of the results of the authorities that came before them. Both of these demanded a new standard of precision, because there were so many examples of

inaccurate reasoning and observation that filled the path of the science in the past. In addition, they believed in the reduction of problems to their smallest constituent parts as a general principle. This scientific method is the one that is used for retrieving biological information from an organism. Through quantifying and monitoring body activity in the moment of interaction with reality we can perceive how the person is reacting when interfacing with an external stimulus like a piece of art. The scientific approach is used as a tool for retrieving medical information that is then used in a creative artistic way, which serves at the same time as an external stimulus fed into the body again. The fact that this approach to make art connects different perspectives of our modern world such as art and science reveals what some artists started to presage at the beginning of the last century and is the transformation of our world but particularly of our soundscapes, slowly invaded by new technologies.

2.3 State of the Art

In the beginning of the 20th century there was an aesthetic movement deeply interested in the revolution that technology was bringing to society and how it would affect it. Their movement was known as futurism and at the forefront of it was Luigi Russolo, an Italian painter composer and inventor. In his manifesto, *"The Art of Noises: Futuristic Manifesto "*[5] he talks about how the new industrialized world is bringing a new palette of sounds that are contributing to the construction of a modern soundscape full of new noises and timbres. Russolo states that, "Nowadays musical art aims at the shrillest, strangest and most dissonant amalgams of sound. Thus, we are approaching noise-sound. This revolution of music is paralleled by the increasing proliferation of machinery sharing in human labor. […] We must break at all cost from this restrictive circle of pure sounds and conquer the infinite variety of noise-sounds." [8] Russolo invites us to embrace the sound as it is: vibrations in the air created by any disturbance of the medium. With this idea in mind, we are no longer tied to make music with only musical instruments but with any sonorous artifact such as an EKG or EEG reader, embracing not only the sound of the machines but also their capability to extract vital information from our body.

After Russolo, in 1966, Pierre Schaeffer both a researcher and composer, published the *"Traité des objets musicaux"[9]* in which he published more than ten years of research in electroacoustic music. He intended to create a new approach to modern music, a multidisciplinary approach that

included both traditional music and Concrete. The term concrete is used to refer to a compositional method based on concrete sources or material (recorded or synthesized sound). The term goes in opposition with Abstract music, which is composed in an abstract and intangible world of notes and harmony (score). Schaeffer also introduced the notion of a sound object: "If someone plays us a tape, which plays a sound whose origin we are unable to identify, what are we hearing? Precisely what we are calling a sonorous object, independent of any causal reference, which is designated by the terms sonorous body, sonorous source or instrument."[9] This approach to music and sounds reveals a change from a representational to a neurophenomenological point of view that comes from the field of neuroscience.

Table 1. Intensions of listening

	Intension d'écoute	
	Abstract	Concrete
Objective	Comprendre to understand	Écouter to listen
Subjective	Entendre to mean	Ouïr to hear

Schaeffer proposes four different models that humans listen to and that can be changed by the focusing on peculiarities of the sound, as we see in Table 1. To listen corresponds to associating a sound to a specific physical object; this is what Schaeffer refers to as sound objects. To hear corresponds to unfocused listening, the state that most of the people are in most of the time, where they are receiving sound vibrations in their ears but they are not processing that information so it just becomes irrelevant data. To understand is the ability of encoding and decoding information within the sound such as how languages work. It is the ability to transmit a message through sound. Finally, to mean is the action of giving an intention to the message transmitted, it is a sound generated with a subjective purpose but does not always refers to a tangible element. Other musicians such as Daniel Barenboim support this approach: "In the same way that is possible to look and not see, in hearing one may hear and not listen. Listen, is hear accompanied by thought, just as feeling is emotion accompanied by thought."[10]

Schaeffer's ideas reveal a key component to how we receive reality, we have the option to voluntarily accept external stimulus like light and sound and analyze them, or the option of repealing them until they point where they invade our physical reality so much that it is impossible to ignore them any longer. Again, this symbolizes the abstract and subjective reality against an objective and concrete world that we cannot change. This symbiosis between these two realities represents a field that some artists started to explore in order to bring new artistic ideas into science and vice-versa. A great example of combining science with art, is the architect, mathematician, and composer Iannis Xenakis.

2.4 Xenakis

In 1958 the Dutch company Philips, hired the architect Le Corbusier to build a structure to host a multimedia modern show for the world's fair that took place in Bruxelles that year. Since le Corbusier was already busy with another project he looked for a second person to undertake this task and at the end, Iannis Xenakis led the whole project. Greek by birth, Xenakis established himself in Paris, where he gained a reputation as an engineer and architect, but also started studying composition with Darius Milhaud and Olivier Messiaen. Messiaen saw that Xenakis didn't have any knowledge of traditional harmony or notation so he suggested him to follow and develop his own language which allowed Xenakis to transcended the limitation of traditional music and became a pioneer in introducing modern techniques into music such as informatics and mathematics.[11]

The Philips pavilion was then an opportunity for Xenakis to combine his two passions, architecture and music. His piece *"Mestastasis"* is Xenakis' first big orchestral composition and was completely different to what was being done at that time which was serial and post-serial music. Instead of a series of organized pitches, Xenakis treated his music as sound blocks or clouds that would vary with the use of glissandos thus giving continuity and constant texture variation. The score of Metastasis is a graphical score where hyperbolic shapes are created using straight lines describing the tangent points of a curve, a very common mathematical design as seen in Figure 4.

The Philips Pavilion was constructed using the same concept; straight lines of concrete would create nine hyperbolic parables that constitute the building itself. Inside the building, there was room for around 500 people who would witness the first modern immersive experience of our days. Images from all over the world where shot at the walls of the pavilion while Edgard Varèse's "Poème électronique" was playing. During the intermission between each one of the shows one of Xenakis' compositions was also being played (Figure 5). The importance of this work lies in that it reveals the conjunction of math and music in modern times just as Pythagoras did during his time by revealing mathematical models in musical harmony.

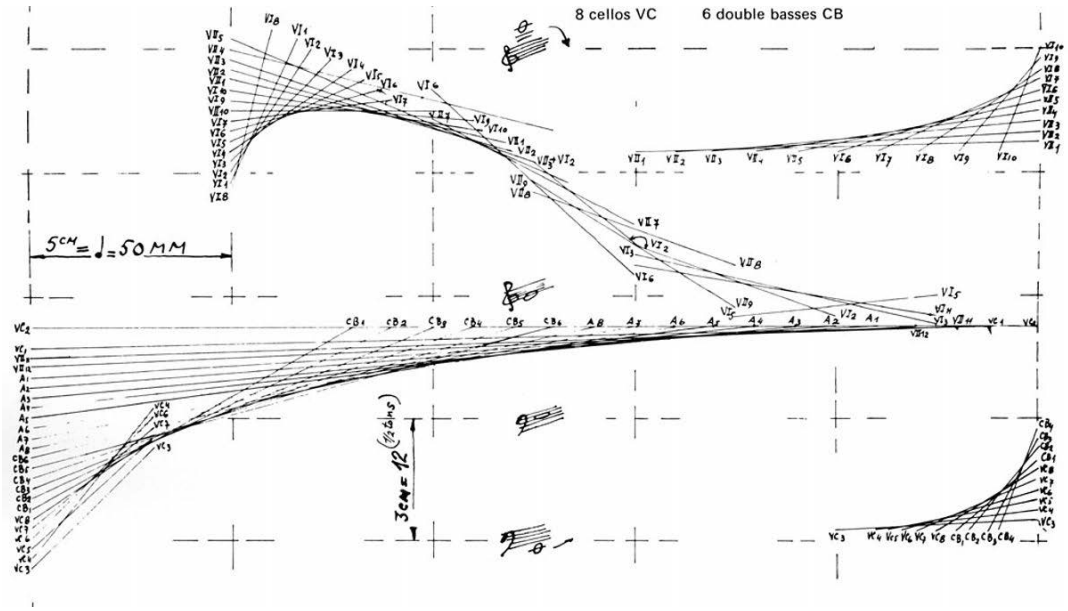

Figure 4. Metastasis' score

In addition, this world's fair was the first one after an 18-year absence due to World War II. Because of this, the Bruxelles 1958 world's fair is considered one of the first times different disciplines such as cinematography, art, music and science collaborate with each other in order to deliver a first approach to multimedia arts.[12] Xenakis used music like architecture and vice versa, designing music for pre-existing spaces as well as designing spaces for specific music and performances.

Figure 5. Philips Pavilion

2.5 Contemporary art

Today many artists are breaking the boundaries when it comes to incorporating new technologies in their art. In 1948, in his book *"Cybernetics or Control and Communication in the Animal and the Machine"*[13], Norbert Wiener defined cybernetics as the science of adaptive, feedback-based control. Cybernetics takes the view that control in complex environments must be conversational. It requires not just action but also listening and adaptation. The cybernetic model of control is circular; decisions depend not only on how well people carry out their intentions but also on how environment responds. When this conversation happens inside an organism the outcome is known as a cyborg (cybernetic organism). A cyborg is a symbiotic relationship that exists inside a cybernetic organism that usually incorporates technology as part of their integration.

Artists like Stelarc (Figure 6), have embraced the technological revolution and implemented every new discovery into his art. Stelarc is a performance artist who has visually probed and acoustically amplified his body, including three films of the inside of his body. Between 1976-1988, he completed 26 body suspension performances with hooks into the skin. He has used medical instruments, prosthetics, robotics, Virtual Reality systems, the Internet, and biotechnology to engineer intimate and involuntary interfaces with the body. He explores Alternate Anatomical Architectures with augmented and extended body constructs. [14] Stelarc

pushes the boundaries of human mind and body in conjunction with the invasive technologies that he uses. Indeed, most of his work relies on the insertion of an external system inside the individual that then limits the user to a submissive role in which he seems to be in service of the machine and not the opposite. This invasiveness of technology inside the human body reveals a more futuristic and dystopian approach in which it seems that after created, the creation could take control over the creator.

Figure 6. Stelarc

At the same time, another person was exploring the human body and mind as a medium for performance, the Serbian Artist Marina Abramoviç (Figure 7). Abramoviç has pioneered the field of performative Art starting in the early 70's using her body as an artistic medium. She has presented works in the form of performances, sound, video, photography, sculpture, and "transitory objects for human and non-human use" in museums and exhibitions all over the world. She opened the path for new approaches to use bodies to explore and transcend physical, mental and psychological limitations[15]. She set up the base for artists to creatively express themselves through the human body and its interaction with the environment in which the performance is happening.

Figure 7. Marina Abramoviç

A more modern artist that explores the human body as a medium for performance is Neil Harbisson (Figure 8). Harbisson was born with a condition known as achromatopsia, which causes him to only be able to see in greyscale. Coming from a musical background, in 2003 he starts working on a system that allows him to translate color frequencies into sound frequencies. Using a camera that he calls his "third eye", he detects colors and sends those color frequencies through an antenna to his occipital bone, transposing the color frequency to a hearable one, transforming colors into sounds. This artificial synesthesia allowed him to finally see colors that he associated to sounds and through a biofeedback process, he was able to develop a sound memory and a full palette of colors. After living with that system for more than 10 years now, he states that the moment when he felt that his brain and the software were working as one, is when he started dreaming about colors.[16]

Figure 8. Neil Harbisson

This is a perfect example of cybernetics being used for artistic and scientific statements; Harbisson's work embodies the biofeedback paradigm. A cyclical and empirical interaction in which the system is presented with different types of inputs, of information about the system itself or its environments. This cycle is repeated constantly since our inception and continues to be repeated and updated perpetually until the system dies. A social analogy to this idea is that our constant learning process and the people that we interact with, programs a direction in which the individual will grow to, influencing himself by his own decisions but also by how he interacts with others. That creates a symbiotic relation between the system and its creator. This is in my opinion the Aristotelian approach to reach the world of ideas that his master Plato thought invariable.

2.5.1 Biofeedback

David Rosenboom explains biofeedback as the "presentation to an organism, through sensory input channels, of information about the state and/or course of change of a biological process in that organism, for the purpose of achieving some measure of regulation or performance control over that process, or simply for the purpose of internal exploration and enhanced self-awareness" [17] The term "biofeedback" became widely known in the 1960s, even if biofeedback retrieval was happening since the 1920s. Scientist recognize the ability of humans and animals to voluntarily learn how to control or influence the behavior of biological vital signs such as heart rate, blood pressure, brain waves amongst others.

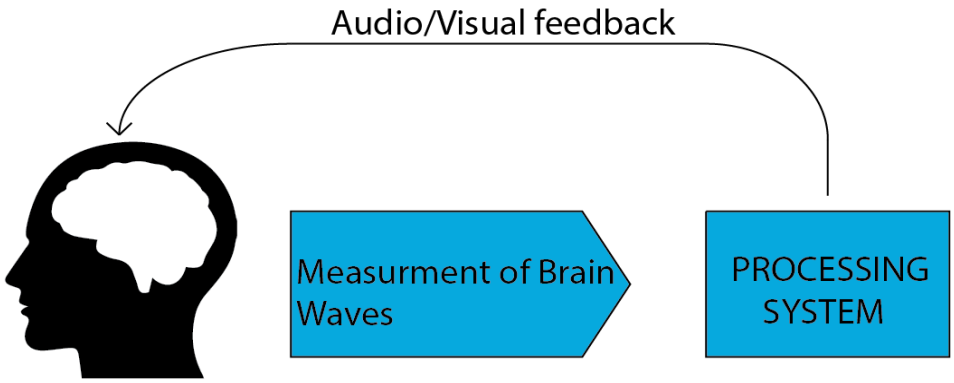

Figure 9. Neurofeedback

Electroencephalography (EEG) is the measurement of brain activity with electrodes that measure they variation of voltage over the scalp generated by neurons. The method of biofeedback that uses EEG is called neurofeedback (Figure 9). This information is catalogued in different types of brainwaves depending on their frequency. As stated previously, biofeedback is the main method utilized in this research since it allows the extraction of data from the human body system to both monitor its reactions to the environment and use that information in a creative artistic statement. Biofeedback history and its applications will be covered in greater detail in Chapter 3 since it exposes common biofeedback systems and applications.

2.6 Summary

This chapter has exposed a journey through time exploring the different approaches that people have attempted to explain what is art and what is science. The Greek philosophy that is embedded in Platonic reasoning suggest science to be a seeker of hidden, unmodifiable truth; while the line that fallows the thoughts of his disciple suggest that reality is a subjective construction and that through experimentation we create our own. Art is an experimental field where there are few or no boundaries; therefore, art provides a creationist platform for human creativity to be unleashed. Despite having different points of views, this chapter has shown that art and science also share a duality and reciprocity that people have been interested to explore at different times in history. Science indeed, has become more accessible and information is at the reach of everyone nowadays. This may be observed in the work of contemporary artists-scientists that use their bodies as mediums for artistic and social expression. These artists use both their empirical and rational interaction with reality to construct their own personal one. This kind of approach to what's real is what is explored through the original work presented in this thesis, with the purpose of creating an individual socio-artistic statement that defines who I am.

Chapter 3

Biofeedback Music System

"To ask questions about basic, and omnipresent human ability is to implicitly ask questions about evolution. Animals evolved certain physical forms as a response to their environment, and the characteristics that conferred an advantage for mating were passed down to the next generation through the genes"

--Daniel J. Levitin (2006)

Our present mind and body have gone through thousands of years of evolution, responding dynamically to their environment. Our minds have co-evolved with the physical world, changing in response to ever-changing conditions. This is the Darwinian idea of evolution, in which current species have gone through millions of years of adaptation and progress with their environment. Our bodies and minds have developed certain abilities that have helped humans survive through thousands of years of adaptation to our environments. As Chapter 2 reveals, scientific discoveries have opened people's minds in the past century as they have never been opened before embracing both Platonic and Aristotelean views. People create hypothesis which are then tested with experiments to reject or support theories. This testing process generally involves prediction and experimentation, and evaluation of how well new data conform to the predicitons. Art and science are also part of this evolutionary process since they represent the abstract and concrete representations of our current place in the evolutionary line. This means that if we look at a specific piece of art or scientific theory in any time of history, it would reveal the interpretation of reality that people had in that era. With the progress of technology alongside human intelligence, the distance between art and science is reduced, and they are being merged to deliver new astonishing works and construct different perspectives of reality. These

new ways of seeing reality and new technologies that allow us to interact with it, have led us to explore new fields that didn't even exist and would never have existed if it wasn't because of technology.

This chapter will first explore the technologies that allow biofeedback with EEG and EKG signals. For this purpose, the implementation of both consumer and custom made devices will be implemented. The creation of custom made biofeedback devices allows me to put my own personal input in the biofeedback outcome, thus providing even more immersion into the whole experience of reality through a biofeedback system. The creation of these devices also provides the necessary tools to create a personal music system that includes the performer and both EEG and EKG signals. This final music system is embedded in an audio/visual, performative composition entitled Cyborg. The Cyborg system represents the biofeedback paradigm of constant interaction with reality in order to create new concepts and artistic stimulus.

3.1 Biofeedback

Biofeedback is one of these new technologies that were created in the last century and that allow us to see what is going on inside our bodies. New developments in neuroscience and brain-computing music interfacing (BCMI) have been derived from this tool and are part of the innovative fields that incorporate the conjunction of art and science. Until the mid 20th century the study of brainwaves was limited to a systematic analysis and amplification of them, however around 1975 David Rosenboom introduced a system whose parameters were influenced by shifts in EEG signals due to the performer's selective attention while performing with his instrument.[3] He explored the hypothesis that it would be possible to detect certain components of our cognitive processes when performing a task, in particular when performing an instrument or when listening to music. That information is hidden inside layers of different EEG signals, including noise, which then brings the challenge of retrieving meaningful information from this system. Different approaches have been used to retrieve that important information from noisy EEG signals, but for this project, the technique implemented is known as Machine Learning. Nevertheless, different external artifacts that compromise the clarity of the EEG signal always obscure EEG signals. Physiological artifacts come from the body and may occur when the patient is drinking, eating, smiling, frowning, blinking, watching TV, playing

games, sweating, sleeping, and even breathing. This means that in order to have a clean and relevant EEG signal the user must be completely relaxed and isolated from any artifact that can create and disturb the electromagnetic field around the user. This is a problem for the implementation of this particular system, since the final goal is to have a cyborg system in which the performer can perform traditional acoustic instruments while connected to biofeedback apparatuses that apply some kind of control or modification to the traditional acoustic performance. Indeed, if I only support the system on the EEG biofeedback, it will then cause noise and distortion in the information coming from the performer since, acoustic performance with an instrument requires physical force and movement from them. This situation has been evidenced when using the MUSE headband detector that transmits brainwave signals through Bluetooth from the device to the computer and enables interaction with them. When testing MUSE, it became clear that any muscular movement in the forehead such as smiling or lifting one's eyebrows would cause the electrodes to stop listening and stay at a stationary value.

This is the reason why my biofeedback audio/visual system implements another type of biofeedback known as electrocardiogram or EKG. This biofeedback method has been used very little in the arts [18], maybe because of the prescription that, the heart is just a dumb muscle under the control of the brain that does a repetitive action over and over again; however very relevant data can be found in EKG signals, like arrhythmia and other medically important information. Nevertheless, the most relevant information, for me, is the heart beat tempo or beats per minute. This information allows for an immediate association with beats per minute in music or what is known as tempo. The heartbeat reveals the current physical state of the user, whether or not he is relaxed, or if he is engaged in a type of physical activity such as playing an instrument or doing a sport. The heartbeat rises as the user is excited and lowers its tempo when the user is calmed and relaxed. This allows a straightforward mapping of the heart beat rate to the main tempo of the music that is being performed. This methodology in conjunction with the EEG will be the basis of the cyborg musical system presented later in this chapter.

3.1.1 Electroencephalogram (EEG)

EEG is a type of moving electrical potential recorded from the scalp surface. It is generated by neuronal activity in the brain and is very small in amplitude (in the μV range) due to attenuation

caused by the skull and scalp. It is categorized in different types of signals depending on their frequency and amplitude. Other types of data can be retrieved from EEG such as evoked potentials, which are a specific type of transient signal following the onset of a visual, auditory or another sensory stimulus. Usually it happens between the first 100 to 700 milliseconds as short transient waves. Since it produces such a low voltage, the measurement of event-related potential (ERP) needs a more intrusive biofeedback technique that puts an electrode in direct contact with the skin right on the vertex of the skull. With modern EEG sensors such as the MUSE headband it is possible to detect different types of complex, long term coherent waves that have been catalogued as different types of brainwaves depending on their frequencies and are associated with different states of mind (Figure 10). These brainwaves, however, do not show response to external stimulus as the evoked potentials, or event-related potential (ERP), because they behave as a continuous stream of data (4 seconds approx.) and not as a discrete event like the ERP.

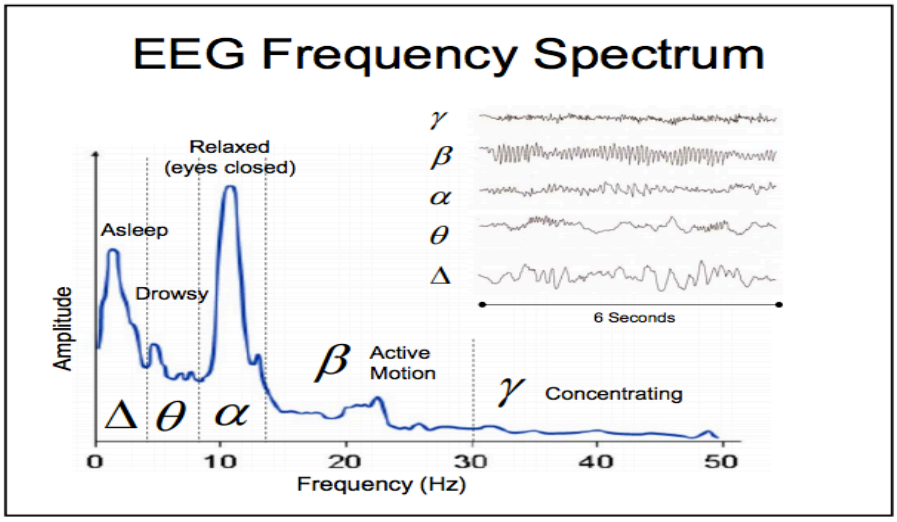

Figure 10. Brainwaves classification

However, it is still possible to detect reactions inside the brainwaves spectrum to external stimulus. Individual types of brainwaves do not provide relevant information about external stimulus, therefore it is necessary to analyze and observe them as a whole. Historically, people have used different techniques to retrieve meaningful information from noisy EEG signals, such as autocorrelation functions calculated by successive time delays of input data in a multistage delay line. However, a more contemporary technique known as Machine Learning may be

applied here. Machine Learning is the process of inferring patterns from incoming data in order to recognize different patterns in the overall brainwave spectrum that respond to different external stimuli. These are known as supervised learning algorithms (Figure 11). The training data represents prerecorded examples of the system's data for different given stimulus.

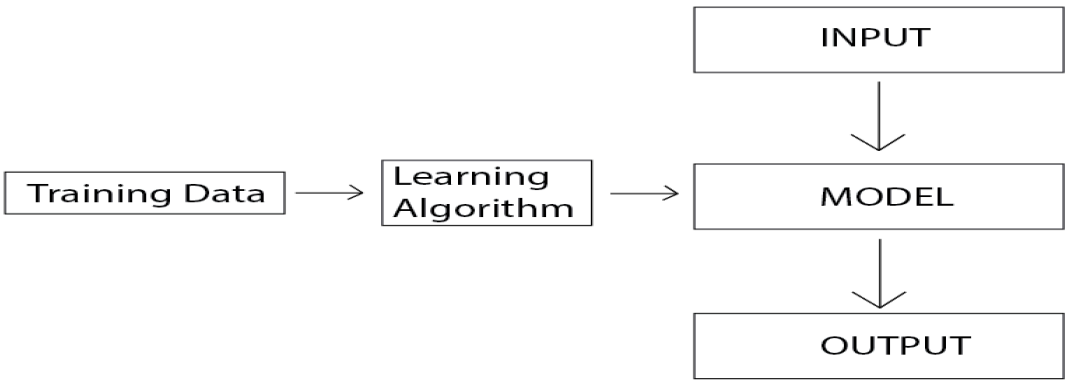

Figure 11. Supervised Learning Algorithm

Different software libraries are available for using Machine Learning, for this particular project I used a modern software developed by Rebecca Fiebrink called Wekinator [19]. Wekinator is open source software that listens to incoming OSC (open sound control) data and trains different models depending on which algorithm you chose to train those models. It has different built-in types of algorithms depending on the case you might want to use. In this case, the chosen algorithm is the Neural Network (Figure 12)

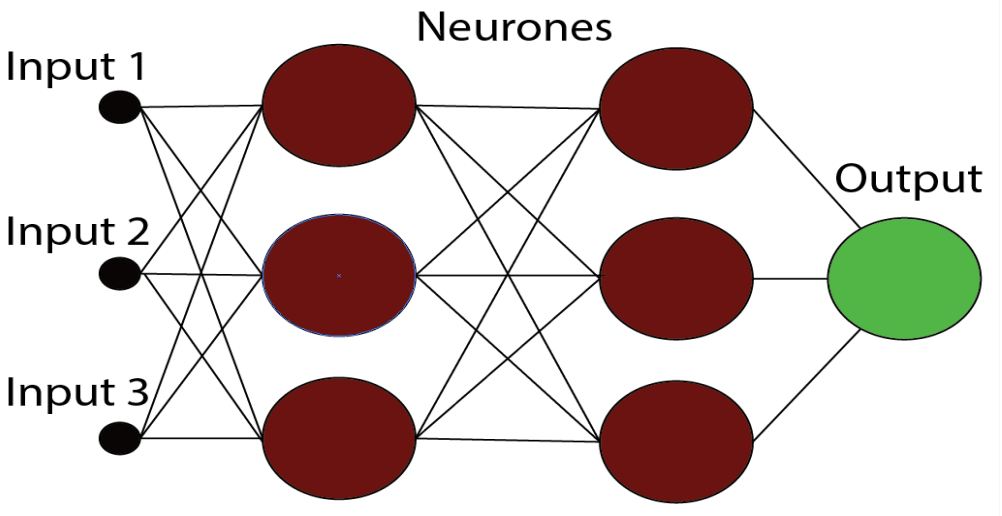

Figure 12. Neural Network

Neural networks are constructed of layers of interconnected artificial neurons. The input layer receives input from a given environment, the output layer outputs values to that environment, and in between those layers there are any number of hidden layers, which communicate with other neurons in the network. Refer to Rebecca Fiebrinks' thesis [19] for more information about Wekinator and Machine Learning. For brainwave measurement, there exist different commercial tools such as MUSE headband or Neuro Sky that allow the wireless transmission of brain signals to the computer. However, these technologies are not that cheap and require knowledge of software and hardware that not everyone has. That is why as part of my research I developed and built a homemade EEG reader and amplifier. It basically consists of 2 electrodes attached to particular locations in the user's skull that detect variation in voltage potential, and a third electrode acts as floating ground. The signals from the electrodes are amplified through an instrumentation amplifier and then filtered with a couple of low pass RC filters as seen in Figure 13. The instrument outputs amplified brainwaves that can be analyzed through Fast Fourier Transformation (FFT) but information that is more relevant can be extracted if data are analyzed through a memory delay line that averages the value of each one of the brainwaves inside the spectrum.

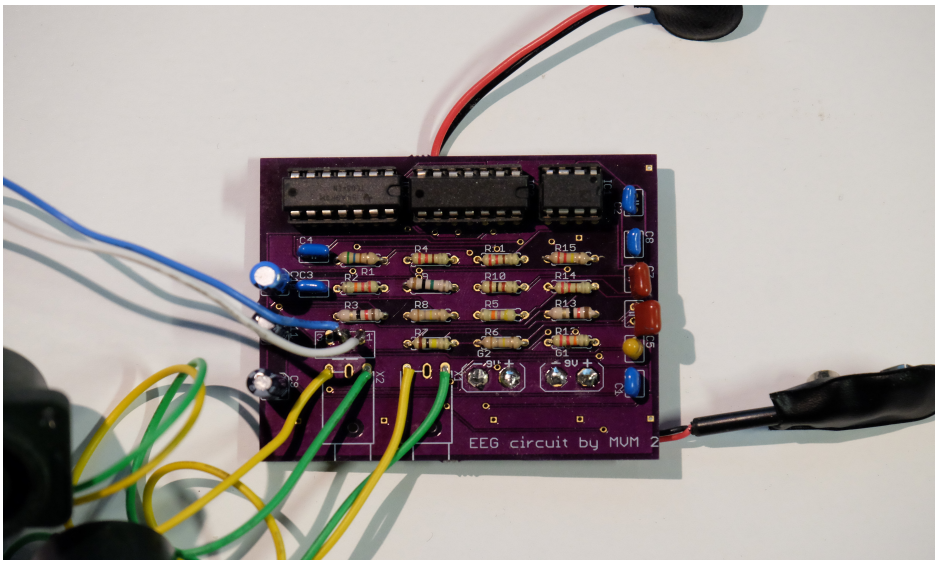

Figure 13. EEG circuit

Brainwaves carry relevant information about how our brain is behaving and about our current state of mind. Modern tools are being developed to help people acquire control of their state of minds through meditation. Even if some of these modern tools come with simple video games

that you can play with your brain, their main purpose is to deliver healing methods for people with medical conditions. With the development and implementation of an EEG discrete circuit, I am trying to bring this technology to a cheap reproducible state where many of them can be fabricated and implemented at the same time for all the musicians of an orchestra for example.

3.1.2 Electrocardiogram (EKG)

Electrocardiography is the technique that is used for monitoring heartbeat and blood pressure in our systems. In opposition to how brainwave detection works, heartbeat is a louder, more perceivable human biological signal that is also discrete in time; whereas brainwaves behave in a more continuous flowing behavior. Research has shown that attention to some comfortable stimuli is associated with a significant drop in heart rate. Heart beat works then as a clock, as a tool for keeping our biological system synchronized.

Indeed, all living things have their own Circadian clock which makes it possible for organisms to coordinate their biology and behavior with daily and seasonal changes in the day-night cycle. The body's clock is responsible for more than just sleep and being awake. Other systems like hunger, mood, stress, heart function, and immunity also operate on a daily rhythm. A "master clock" in the brain coordinates all the body clocks so that they are synchronized. The master clock that controls circadian rhythms consists of a group of nerve cells in the brain called the suprachiasmatic nucleus, or SCN. The SCN contains about 20,000 nerve cells and is located in the hypothalamus, an area of the brain just above where the optic nerves from the eyes cross.[20]

A master clock is a clock that provides timing signals to synchronize slave clocks as part of a clock network. Virtually every digital audio device will have an internal digital clock. Those clocks are generally based on accurate and reliable piezo-electric quartz crystals. In order to detect heart-beats, there exist different approaches; but for this project the development of a custom made interface was the choice, allowing once more to be immerseed in the biofeedback process by developing the biofeedback device. Built in the open source hardware/software Arduino, the instrument uses three electrodes that are attached to the body in a specific location known as the Einthoven triangle (Figure 14).

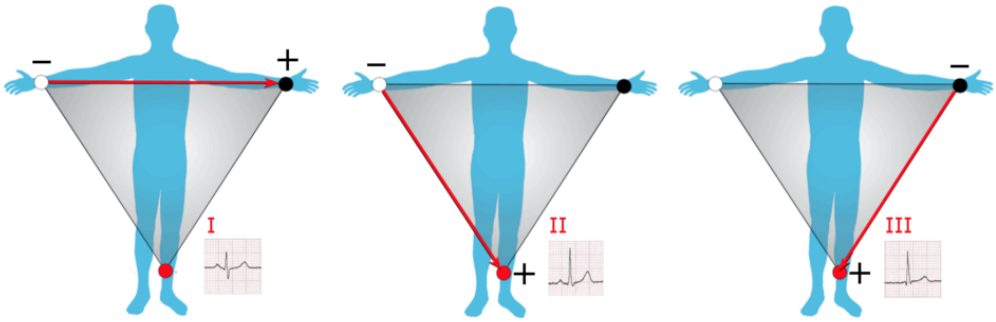

Figure 14. Einthoven's Triangle

Willem Einthoven was a Dutch doctor that accurately measured heartbeats for the first time in 1903. He developed a technique in which the heart is located at the center of two measurement points and a third electrode creates a ground between those two points when all the voltages are summed. Depending on which one of the electrodes is chosen to be ground, the measurement of the heart beat will be different as seen in Figure 14.

Figure 15. EKG instrument (HeartDetektor)

Using the custom made heartbeat detector (Figure 15), a main program was created in which both EEG and EKG signals are received and are in control of different parameters. A main sequencer is constantly running and receiving the heartbeat rate as the tempo source for it. If the

user gets exited, his heart rate rises; thus the tempo of the system is incremented as well. If the user is quiet and still, the opposite reaction happens and the system comes to a quieter state.
The sequencer can be programmed to play samples like a drum machine or also be completely arrhythmic, playing synthesized sounds that are created and controlled by brainwaves input. This arrhythmia also corresponds to an actual arrhythmic heart behavior that I personally have that makes the system not to be quantized in tempo. Nowadays, modern software provides us with the possibility of subdividing tempo to a perfect quantization of it. However, there is still a predilection for human input as a source for recordings and compositions to the point that some digital audio workstations have included a "humanize" option to add some imperfection to the audio, thus making it more humanly imperfect.

3.2 Cyborg I

From a more poetic and ethical perspective, heart and brain are usually associated with different concepts. Heart is where our emotions and feelings and things that we cannot control happen, while our brain is where all of our logical and decision-making processes happen. That separation of these elements correlates to the separation that is implied between art and science. Since the brain has been conceptualized to be intellectual and the heart to be passionate, by implementing a biofeedback system using EEG and EKG, it represents the union between both worlds (art and science) and allows retrieving information at the point of intersection between them. One exists because the other exists; they are dependent on each other meaning that one cannot work without the contribution of the other's work.

Cyborg represents the set of live performances that are intended to be performed with the conjunction of EEG, EKG, and human performance. It represents an approach to live audio/visual performance in which the performer is composer at the same time, and its live output is influenced by the environment in which they are performing. The performer connects both the EKG and EEG detectors to their body in order to integrate them into the live performance. This adds a new performative element; it is also possible to incorporate the process of putting on all the biofeedback devices into the piece after it has already started. That way it is possible, especially for the audience, to identify a sonic or visual reaction to the connection of these devices.

Once the performer is wearing the biofeedback devices, the data coming from the devices is received in the main computer that then processes all the information into audio/visual stimuli. In order to break the imposed, scientific concept that our brain is the master clock and the heart is a slave to it, this particular biofeedback system works the other way around. The heart is in control of the whole biofeedback system; this means that whatever behavior is controlled by the brainwaves is also being affected by the master tempo or rhythm given by the heartbeat. The main program running the Cyborg software is Pure Data [21], an open source visual based programming environment for digital art, specifically sound and music. A 16 step sequencer is controlled by the heart rate. The state of relaxation or excitation of the performer, determines the tempo of the sequencer. Every four steps of the sequencer, a synthesized kick drum mimics the heart beat sound; but its frequency is mapped to an ultrasonic sensor built-in the heartbeat detector, which means that the sound of the heart can become a high pitch frequency as well. Once the heartbeat is detected and mapped to the kick drum, the brain becomes subordinated to the sounds that are being generated by the heart. Using the same 16-step sequencer, each step is assigned to the root pitch of a saw-tooth oscillator. Saw-tooth waves are characterized by having both even and odd harmonics over their spectrum, making them very interesting for subtractive synthesis. The amplitude of each one of these harmonics is controlled by a specific brain wave that makes the spectrum move around preset fundamental frequencies.

Next in the sound chain comes a band pass filter that takes in the sound coming from the sequencer and filters it. Alpha brain waves are the most explored and used in history of BCMI, they are associated with visual engagement and relaxation states. Alpha signals are analyzed through an envelope follower whose output controls the frequency of a resonant band pass filter. The result is a low frequency drone that changes its timbre constantly depending on the intensity of the brain waves and on which harmonic is activated, which in turn, is controlled by the sequencer slaved to the performer's heartbeat. After heart and mind are connected and in control of a parameter in the system, the performer can introduce his acoustic or digital instrument into the composition. Through interaction with a MIDI controller, the same performer or a second computer performer can sample the live musical instrument and then apply granular synthesis to the recorded samples (Figure 16).

The piece continues to grow, as new material is being sampled and processed by brain control until it reaches a climax of noise and saturation where the performer is fearing being overtaken by the system and the devices attached to him. At that point, the performer removes all the biofeedback devices from his body and lets the piece slowly fade away.

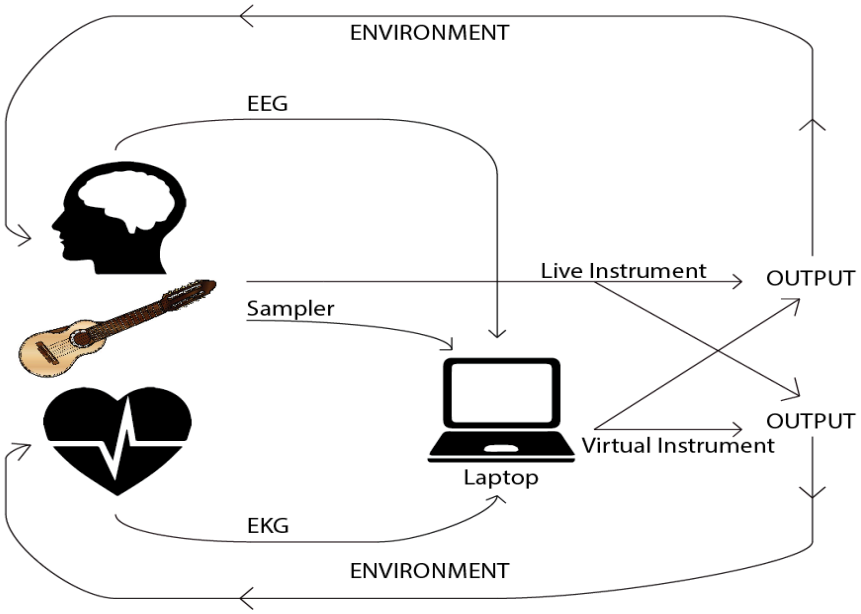

Figure 16. Cyborg Diagram

This piece constitutes a personal exploration about how to embrace your limitations and flip the coin in order to take advantage of them. The heart condition that I was born with set up the base for a lifetime interaction with biofeedback devices, particularly EKG. By taking a personal element that defined me since birth, and merging it with a lifetime process of becoming a musician and artist, I adopt and implement the biofeedback cybernetic paradigm into my artistic statement. Cyborg then, represents also the expression of my current reality in which my research work led to introducing all these theoretical ideas into my artistic performance. By using scientific tools such as biofeedback and linking them with musical and artistic expressions, the performer becomes the space of exploration for knowing what reaction occurs when art and science collaborate with each other.

3.3 Biofeedback system conclusions

This performance represents the biofeedback paradigm that I am exploring with this same system. The tool created with a medical intention becomes the musical device that manipulates not only the performance but also the performer's latent state of mind. The environment is also constantly influencing the performer; thus, the performance is also affected. The disconnection from the devices at the end of the piece demonstrates that the system and the music cannot exist without the performer who is primordial to the system. Heart surgery at birth determines a shocking first interaction with reality that was and is present in every moment of my life and will always be there in future times. The submersion inside medical equipment throughout my whole life led me to be intrigued about knowing how my body works; and that curiosity, combined with an artistic input such as music, provided enough interest and satisfaction to pursue an artistic statement based on that. In this way, I feel there is a connection between me and the way that Harbisson (see Figure 8) embraced his condition to become the first Cyborg. Indeed, Harbisson's first interaction with reality set up the base for a lifetime interaction with a black and white world. This made him want to research and develop a solution for his condition. After he found a solution using artificial synesthesia to hear colors, he started a process of biofeedback interaction with his new augmented reality.

Art and science once again come to help and to collaborate to provide answers to people's everyday reality. Humans process that delivered reality and through cognition, that reality is re-assimilated and re-expressed and feedback into cognition one more time thus revealing the cyclical process of life.

Chapter 4

Alternate Realities

As it was exposed in Chapter 1, the arrival of new technologies has allowed the possibility to experiment with other new type of sensorial inputs or stimuli to interact with reality. This has provided the possibility to temporarily modify our current reality and be submersed in a completely new environment or the augmentation of an already existing space. This chapter will then expose two different projects exploring augmented and virtual reality, trying to answer the question whether these alterations of reality can be considered as biofeedback techniques since they grab data from different type of sensors and construct realities based on that.

4.1 Augmented reality Ping Pong Table (Pong~Ping)

This first project presents an approach to Augmented Reality, explored through the construction of an interactive ping-pong table installation at the Wave Cave gallery at CalArts in March 2016 (Figure 17).

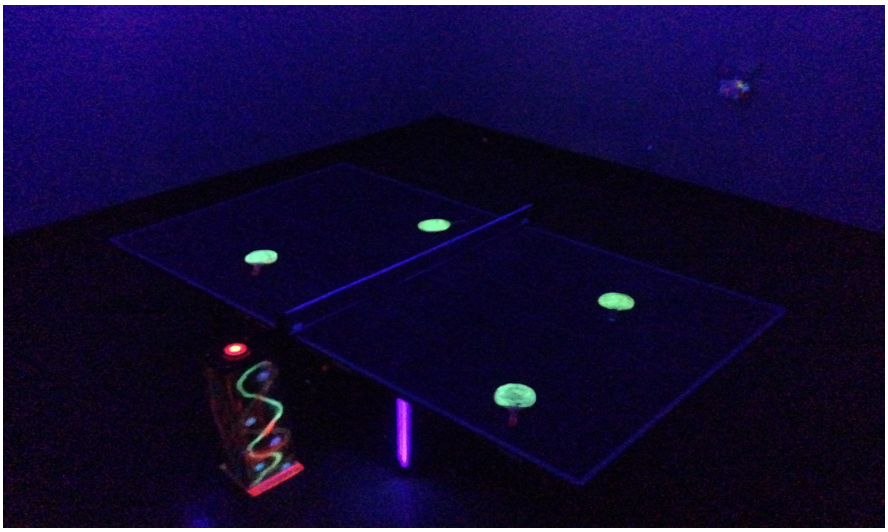

Figure 17. Pong~Ping Installation

Another approach to how we interact with reality that intrigues me is Augmented Reality. Augmented reality is a live, direct or indirect view of a physical, real world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or other data. This approach focuses on playful interactions that involve more than one person interacting and that support physical engagement with the environment. A system or interface is defined as "playful" when users feel challenged or are otherwise persuaded to engage in social and physical interaction because they expect it to be fun.[22]

Sports are one good place where these two realities come together. On one side we have our personal experience with reality determined by our physical and mental states (e.g. sleepy, concentrated, tired), and on the other side we have a more empirical experience determined by the physics of the game (e.g. ball shape, weight, wind). These two interactions with reality provide an output that is what we end up experiencing as a whole, and the way we receive that experience determines how good we are going to perform that particular task, in this case playing Ping-Pong. The rhythm of the bouncing ball and how good you can feel it correlates to how good can you answer the ball (Figure 18).

Figure 18. People playing Pong~Ping

In order to create this augmented reality, we need to have computer-generated sensory input. In this case, we have two types of inputs (Figure 19):

- Four contact mics under the table provide us with sound input.
- Two wireless accelerometers attached to the paddles provide us with movement input.

One big red button installed in a pedestal is next to the table. When users are in the space they are invited to push the button and this will start the main Pure Data patch that process all the sound coming from the microphones and slowly adds sound effects like reverb, delay, distortion, bit crushing among others. The movement data from the accelerometer is also mapped to a frequency-modulated synthesizer that triggers the sound every time the acceleration goes over a certain threshold. The idea is that the sound gets more processed and chaotic as the game goes on until it is over. Then the participants push again the big red button and bring the installation back to its original state. The idea of the two states here provides the users with a choice to how they want their reality to be: chaotic, processed and distorted, or more organic, natural and quiet. The entire sound system is supported by the High Order Ambisonics Library developed at CICM (Centre de recherche Informatique et Création Musicale) and is running in PD-extended (Figure 20). Ambisonic is a tridimensional audio technique that was created in the United Kingdom, in the 70's, but was not very much used until these days where is being introduced into movies to deliver a 3D sonic experience. [23] Ambisonics provides the capability of locating and moving specific sound objects in a simulated three-dimensional space. These sound objects are triggered every time the ball hits the table and start moving around in a circle for a duration that is related to how hard the ball hit the table. This virtual augmentation provides sonic ghostly elements to reality.

Once the installation was up and running people felt an immediate connection with the game. The fact that inside a gallery space there was a ping pong table, created an instant reaction of enjoyment and willing to play the game even for people who was not interested in sound installations.

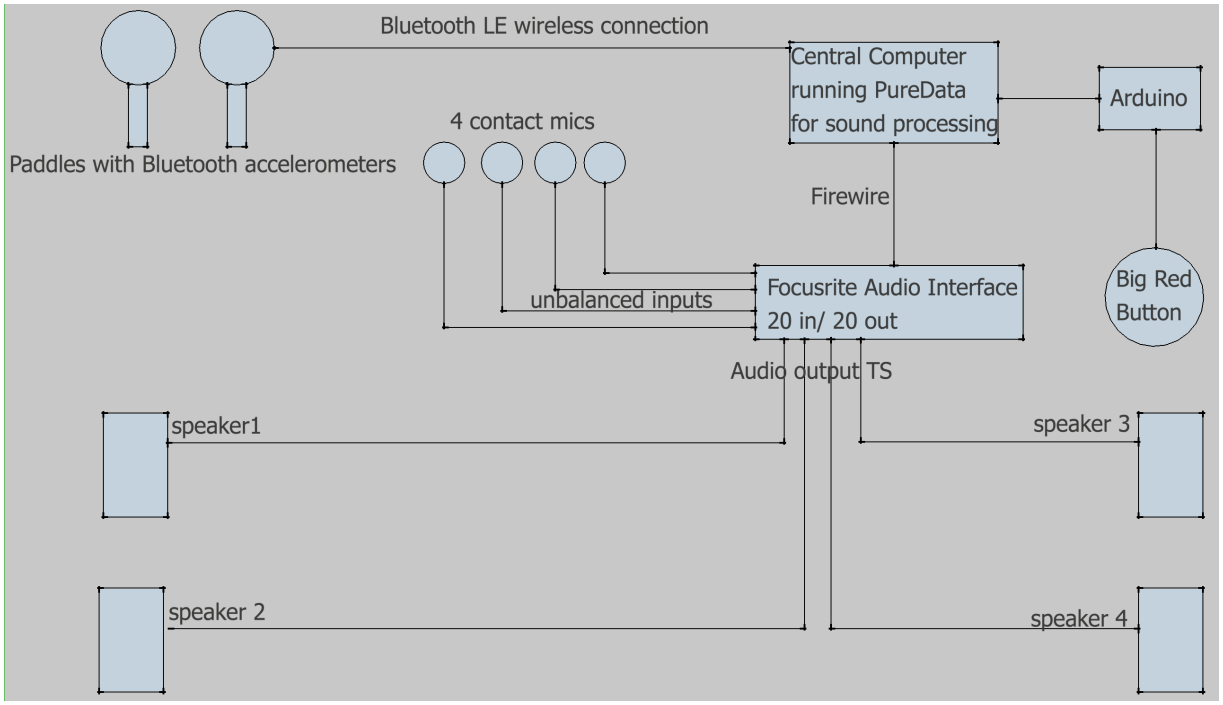

Figure 19. System diagram

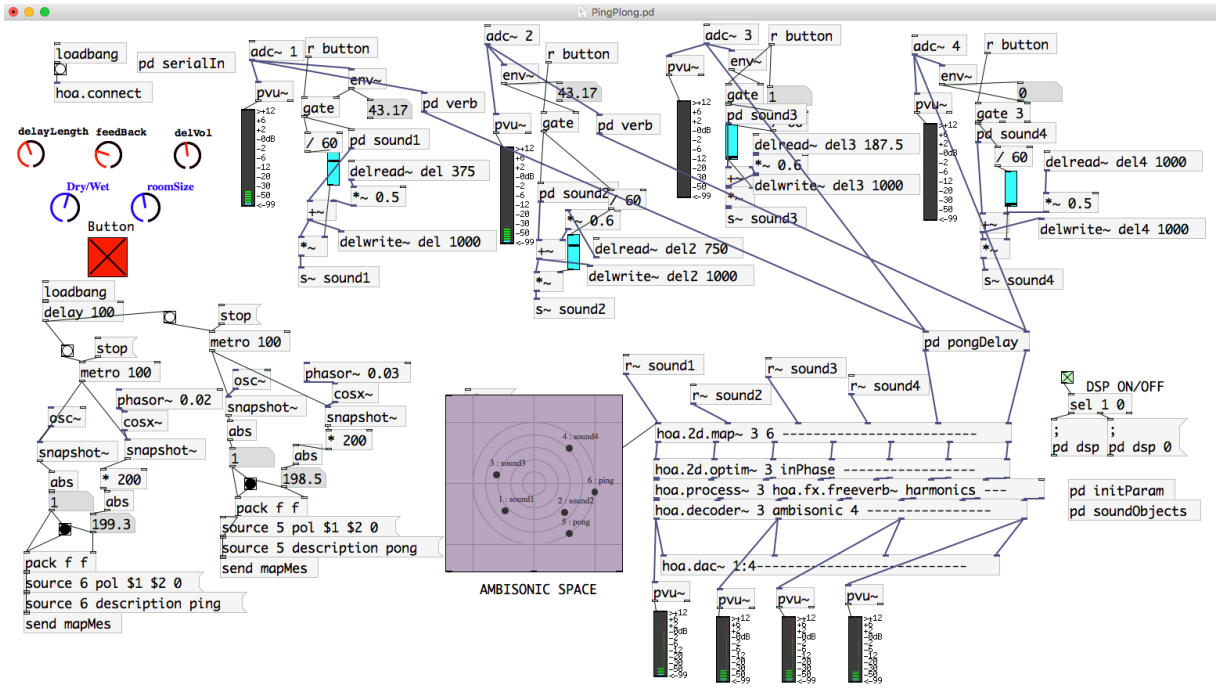

Figure 20. Main Pure Data patch for Pong~Ping

Biofeedback reality is exposed in this thesis as the idea that our environment is part of the cognitive process of progress in life. The scientific method is implemented by grabbing sensor data from our environment and users, and processing it in a computer and using it to amplify our senses and our reality. Augmented reality becomes then the artistic interpretation and implementation of that incoming scientific data that feeds the cycle once again.

Augmented Reality constitutes an effort to create a variation of our real world that we still can relate as our reality but with some augmented and altered elements. It seems that it represents a technological approach to enter altered states of mind without the use of any psychotropic stimulus. This brings up the debate about whether technology is becoming now the psychotropic stimulus that is creating altered and augmented realities constantly around us.

In the world we live in, we already have natural optical and aural hallucinations such as apophenia and paraeidolia. It is possible then to extend and augment our reality through the implementation of our basic senses, however technology is making it easier for us to stimulate and provoke our senses, and our lazy human condition is taking us to embrace that possibility increasingly.

4.2 Virtual Reality development

New technologies always bring new forms to how we interact with our environment. Motion sickness is the illusion of self-motion, in the absence of real motion; it may be a form of sensory conflict. It can be experimented when traveling in a vehicle such as a train, boat, airplane, or even a car. [24] There is a need for an adaptation to that new technology, which is also true in a more personal, empirical way. The first experience a person has with certain technology is unique and will never be the same experience after a second interaction, our brains learn from repeated inputs to adapt our system to those stimuli thus creating a cybernetic system once more.

Virtual Reality (VR) is a new technology that consists in wearing a device on your head that transports the user to a three dimensional world where he is in control of it. The evolution from a 2D to 3D world correlates with the evolution from 2D to 3D in medieval painting like the

work of Giotto. Usually it consists on wearable goggles that have a screen divided in half with the same display but one of them is off set (Figure 21). With the use of lenses, our brain combines the two parts of the screen and creates a single three-dimensional image of the virtual reality environment. This virtual reality field correspond to the whole metaphor that has been exposed in this thesis, two different points of view, or in this case two different perspectives of the same object that combined, creates perceived three dimensional virtual realities.

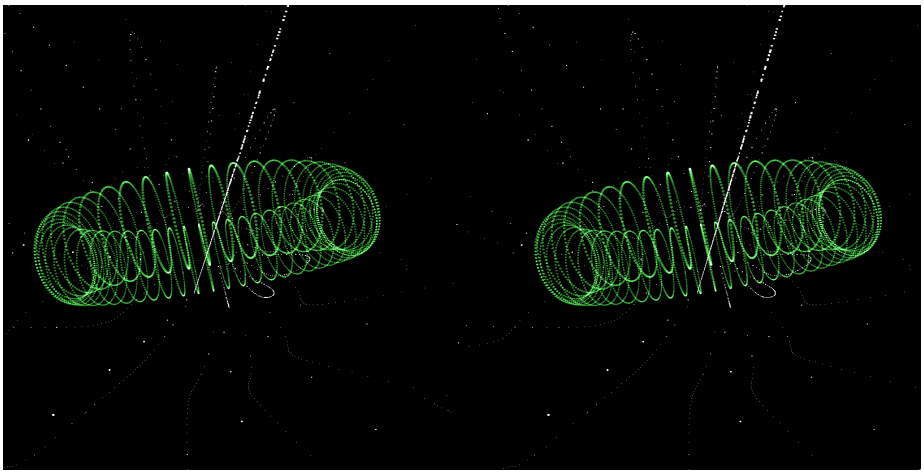

Figure 21. Raw Virtual Reality

Today there exist a couple of different technologies that allows us to interact with virtual reality. The most popular of them are Oculus Rift (Figure 22) and Google Cardboard (Figure 24). An Oculus rifts consists of a viewer embedded in the goggles themselves that is built in the software Unity. On the other hand, Google Cardboard viewer consists in a cardboard viewer that lets the users put their smart phone and run a VR application or website to experience the VR world.

Figure 22. Oculus Rift

Using JavaScript libraries such as threeJS and p5.js it's also possible to create a visual three dimensional immersive experience that runs using webGL inside the smart phones. For three-dimensional audio, several techniques have been proposed; one of the most popular is binaural sound. In binaural technology the Head-Related Transfer Function (HRTF) is the function that determines the reflections and absorption of sound by each person's head [25]. Since no one has the same pair of ears or same head shape this HRTF is different for every person making the binaural sound a very personal and subjective experience. The word binaural englobes a set of tools used for recording, synthesizing and reproducing binaural sounds. Binaural sounds are usually recorded with a dummy head that mimics the physical properties (e.g. density, absorption, reflection) of a human head. Inside the dummy head's ears there are two omnidirectional condenser microphones that detect the sound coming through the ear canal after it was reflected by all the surfaces of the inner and outer ear. This means that it is focused in signals reproduced at the head drum for providing the auditory system a faithful copy of all the information that will be able to process for perceiving and locating objects in space.

For recording these sounds, a custom dummy head was built from a mannequin's head that mimics the rigidity of the skull (Figure 23). Silicone ears were used to mimic the texture of the cartilage although due to Head-Related Transfer Function issues (HRTF) it will never be the same experience and it may vary its fidelity depending on the user's ears and head. HRTF is a transfer function used to describe how the sound reaches our ears and it is related to the shape and form of our external ear. Since each person has different ear shapes the perception of three-dimensional sound will vary for each individual.

Figure 23. Nepomuseno, custom-made dummy-head

This project has been presented at the Gray Area Foundation for the Arts in San Francisco and at the Digital Arts Expo at CalArts. It was exposed in form of an installation where on top of two plinths were several cardboard and 3D printed viewers with headphones as well, as seen in Figure 24.

Figure 24. Immersive Set Up

When users approach the installation, they have to read and follow a set of instructions to navigate in their smart phones to the custom made Github hosted site where the immersive experience happens. This experience consists in a visual abstraction of different particle systems in a three-dimensional void space. These particles slowly move around the user and take

different shapes based on mathematical equations to give different geometrical aspects to the figures. Through headphones, users can listen to binaural field recordings of sound objects from the bay area in the case of the San Francisco exposition, as well as field recordings from the school at CalArts. These recordings are processed through a feature extraction algorithm known as Fast Fourier Transformation that allows to converting audio signal from time domain to frequency domain. Afterwards, these audio features are mapped to parameters of the geometrical objects such as its rotation or location of particles in space. Different experiments are available for the user to choose and involve different approaches to mapping and visualizing this new world.

New technologies always face the challenge of the first interaction with it and Virtual Reality is not an exception. When users are presented to this technology, they need guidance about how to interact with it. This makes it even more difficult to use this technology as an artistic medium because people don't know how to use it and they usually don't take the time to read the instructions which led to people wearing the viewers without any smart phone inside of it. Also the physical collateral effects that people feel such as nauseas and dizziness arises several questions about this new technology; would our coordination and motor skills be affected when we come back to "real" world? Would there be virtual reality addiction or a point where technology is so omnipresent that we cannot longer distinguish between real and virtual?

4.3 Final Conclusions

Virtual and Augmented reality provide a new futuristic approach to how we interact with technology and reality. From an empirical point of view, knowledge comes from our senses, if we extend our senses we can then extend our knowledge. Following that idea one could think that the introduction of new technologies to help or extend our senses would be a good idea and that is true until a certain point. Implementing these technologies for helping people with physical disabilities, such as those that Harbisson (see Chapter 2.5) did with himself, might bring new possibilities and hope for lots of people. However, relying on only those modern technologies to interact with reality can lead to complete alienation of the individual and be completely absorbed by a virtual world. This issue is already exposed in the gaming community

where the players of massive multiplayer online role-playing games (MMORPG) develop and addiction to the game and the virtual community they are part of. [26]

As it has been exposed in this thesis, reality is created by a dynamic interaction with our environment, which is the natural world that we live in. If coming generations are only exposed to augmented or virtual environments they won't be able to develop a reciprocal interaction with the real world they live in, that's why is so important to keep teaching children and encouraging them to develop traditional artistic skills such as writing, playing acoustic instruments or doing sports or any physical activity that makes interaction with our real tangible world. We have come to where we are after a process of thousands of years of dynamic evolution with our environment, if we break that cycle we could face the alienation of each person, hence leading to the collapse of societies. Technology without a critical regard from an artistic and social point of view can easily swift to a different direction than what it was originally developed for, and instead of bringing solutions to everyday problems it could do the opposite.

Chapter 5

Conjectures about the direction of Art into Science

"Art is the Queen of all sciences communicating knowledge to all the generations of the world"

--Leonardo da Vinci [27]

In the previous chapter we covered how scientific paradigms and implementation of those can be transported to the artistic world and be implemented in new creative ways. But previously in Chapter 1, it was also stated that there is another approach in which art is a precursor to discoveries or inventions that science will do after, inspired by artistic ways of seeing life. The artistic state of mind in opposition to the scientific, allows the artist to think outside the boundaries, to imagine new worlds and possibilities. Even if the scientific laws have proved that some particular phenomena are real or quantifiable by some equation, there is always the possibility of re-imagining the problem and arriving at new conclusions. Throughout history, we can see many examples of this.

5.1 Background Artists and Science

For example, the precursor to renaissance artist Giotto is considered the originator of perspective for the domain of arts. Before him all the drawings and paintings in western society were depicted in a two dimensional world. Giotto intuitively started to introduce organization in both horizontal and vertical axis and adds the concept of vanishing point. In perspective, all lines of sight converge on the viewer's eye which is positioned in a stationary privileged location [1]. This new way of approaching art, gave the three dimensional feel of depth to the coming art,

but also provided science with a new perspective that led to start thinking about our world in different dimensions. This is similar to how nowadays new technologies allows us to have art and entertainment that once was in two dimensions, transported into a three dimensional world and even four dimensional with the introduction of haptic stimulus.

In order to explain phenomena scientist usually go to the natural empirical explanation instead of the metaphysical. However, the ability to look from a different perspective and imagine new controversial explanations is what has led to progress and big discoveries through history. A perfect illustration of this is given by Leonard Shlain in his book Art & Physics. As mentioned previously, in his book he writes about how scientists have been inspired by mysticism and aesthetics from particular artists or art movements. He makes a parallel between Leonardo da Vinci and Isaac Newton. The first one was a renaissance Artist and inventor amongst other many things. He contributed to science, in both theory and application, but he is more recognized for his artistic contributions. Newton on the other hand is seen as the father of physics and a huge figure that instituted a new way to think about the world. As Shlain states, both of them grew up with few or no friends but books and that led them to have dreamlike imaginations from which derived a significant amount of discoveries, engineering machines, and multiple different other gadgets. Amongst these discoveries one that they share is the concept of inertia which was first described by Da Vinci and then embraced in Newton's great first law of motion. If Da Vinci did not exist, Sir Isaac Newton would not have had the roots and pre concepts that helped him develop his most revolutionary ideas. In one of Newton's most famous quotes, he refers to all the great minds that preceded him: "If I have seen further than other men, it is because I stood on the shoulders of giants."[28] If Newton didn't imagine outside the stablished rules in a more empirical and therefore artistic way, about an invisible force that brings cohesion to all matter in our universe, he wouldn't have done any of his studies in physics and calculus which led to the famous gravitational laws [29]. Although Newton brought in new theories, he still believed in the Platonic view of universal constants and rigidity set by a creator.

Later, in the beginning of the 20th century another brilliant mind such as Albert Einstein came up with a new paradigm for looking at our universe in which time and space create a fourth dimension known as space-time, that is deformable by the gravitation of each object inside of it.

He contradicts Newtonian physics that space and time were rigid and constant, and proposes that space and time are relative and only the speed of light is constant thus works as a messenger of information traveling the space. This is embedded in his theory of relativity and is depicted in one of the most famous, simplest, and beautiful equations ever $e = mc^2$, which means that energy equals the mass of the object times the speed of light in space by itself. This equation and what it represents constitutes a perfect example of an artistic approach to reality. Einstein had to imagine and creatively design different tests that would confirm his theory that space-time is deformed by the gravitational field of objects in space. His theory also helped to confirm some of Newton's previous observation, and recently scientists at LIGO (Laser Interferometer Gravitational Wave Observatory) recorded the sound of two black holes colliding a billion-light years away which constitutes the first evidence of gravitational waves, another of the imaginary and now proved to be truth, solutions that Einstein predicted a hundred years ago for his approach to describe the universe.[30] One of his most famous quotes that reveals his constant imaginary and creative state of mind is: "Imagination is more important than knowledge".[31]

5.2 Surrealism, Science Fiction and Magic Realism

All these revolutionary discoveries in science led to writers, painters, and other artists to explore the new territories that did not exist before and wonder about new possibilities within those worlds. It is hard to imagine someone less scientific inclined than the Spanish surrealist painter Salvador Dalí. His artwork constitutes a series of realistic drawings, but at the same time artfully disordered images. His fixation with time and space reveals an influence from the relative thinking that Einstein exposed some years earlier. Dalí's artwork is not only full with allegories to time such as melting clocks, sands of time, hourglasses, but also represents an approach to altered realities that had started since Impressionist painters like Van Gogh and Monnet, going through cubism with Picasso and finally creating this movement known as surrealism and whose biggest contributor was Dalí. In his painting "the persistence of memory," he illustrates the concept of deformation of space by time with the allegory of melting clocks as seen in Figure 25. This particular work explores the relativity concept in which, if hypothetically a person could travel at a speed close to the speed of light, that person would start experimenting a deformation

of the space around it because he's approaching the light that originally casted the surrounding objects into his eyes.

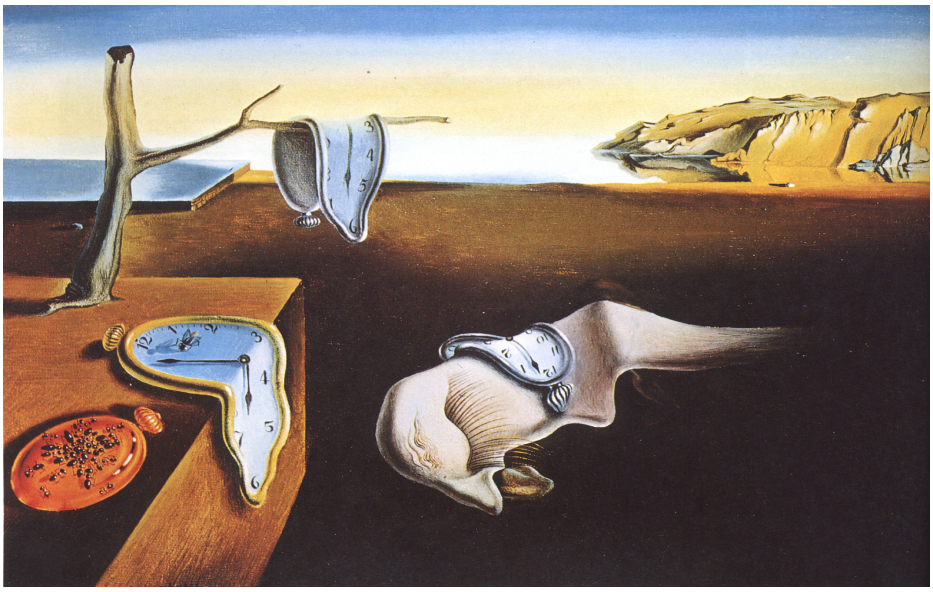

Figure 25. The persistence of memory (1931)

This would cause an elongation of all the objects around the person but also a reduction of past and future time, which would lead to eventually just perceive a single line that is the present constant reality without any other past or future time, when speed of light is eventually reached as seen in Figure 26.

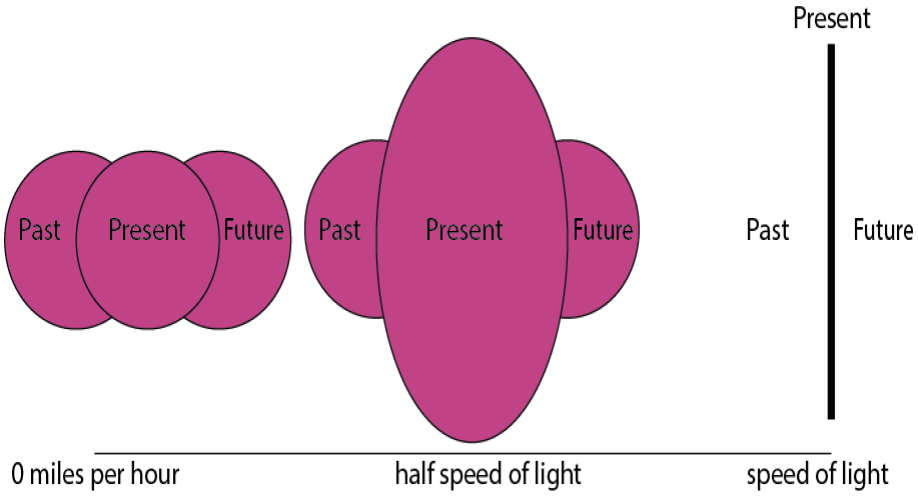

Figure 26. Elongation of space by speed

Other arts such as literature also contributed to the creation of new altered realities based on revolutionary theories. Writers such as Philip K. Dick or Gabriel García Márquez opened the field of possibilities for new explanations or explorations of different realities. K. Dick is renown to be the inventor of the science fiction genre that appeared in the 20th century due to the technological revolution that happened at the beginning of it. He is the author of classic Sci-fi books such as *blade runner* and *minority report* amongst others [32]. He created stories based on hypothetical futuristic societies whose main support for subsisting is technology. The term science fiction refers to an approach to reality that is explained and experienced through science but that is impossible to create in the present because of technological limitations. It is a similar approach to creating physical theories and later prove them, but in this case they create imaginary worlds that we could be eventually reached depending on which direction we move towards the future. Since its creation in the middle of the 20th century, science fiction has also inspired our current reality as some of the objects and technologies that are explained in the novels are coming to life and exist in our world today, which adds another layer to the cyclical relation between abstract ideas and concrete objects.

On the other hand, Gabriel García Márquez was a Colombian journalist and novelist whose primary work as a journalist dealt with Colombia's violent reality. This routine interaction with the real world led him to develop a new vision of his own interpretation of Colombia's reality through empirical interaction with it as a journalist. This is known as Magic Realism and consists in the ability of conveying magic and mysticism inspired by ordinary and mundane reality. His masterpiece *Cien Años de Soledad,* is a great example of it. The novel narrates a cyclical story about a family in Colombia introducing fantastic events within everyday routine and also going through historical events such as civil wars and massacres [33]. Macondo is the place where mystical things happen such as the physical and spiritual ascension to heaven of Remedios while she is hanging the laundry out to dry, or the incestuous relationship between aunt and nephew that produced a pig-tailed baby. Garcia Marquez approach to reality through journalism and empiricism helped explain the mystical longing traditions of a region, searching for links between the physical, rational world and the irrational, intuitive one. These last two examples of science fiction and magical realism show how the exposure to both contemporary art and science has led these two writers to conceive fantastic worlds in which empiricism and abstraction coexist and

give coherence to imaginary worlds. Modern approaches consider that a possibility, a parallel reality just like the ones that modern physicist contemplates with the concept of multiverses, which are parallel realities or universes, to the one we are living in.

5.3 Final Conclusions

The same way that Dalí was influenced by relativity and drew one of the most astonishing artworks in art history, modern physicists and artists also collaborated in the realization of a cinematographic piece where they explored contemporary physics concepts such as string theory and multiverses. The movie *Interstellar* relies on actual contemporary scientific theories and equations to create not only the storyline of the movie but also the amazing visual effects. Indeed, Caltech professor Kip Thorne was asked to collaborate with the production of the movie in order to have science embedded in the construction of the story. Thorne provided the mathematical equations of complex gravity necessary for the visual artists to create the visuals that compose the movie. In doing so, they achieved a level of visual complexity that actually correlates with the theoretical approach to phenomena such as black holes and wormholes. By being able to look at these new renderings, Kip was inspired and created new scientific theories. [34]

This chapter has served as a way to expose the reciprocity of art and science. In previous chapters, the exploration was envisioned on how science affects art and our rational reality. Here it was revealed that the other approach of art into science is as valid and has been used by mankind throughout history. Art and Science constitute then a cyclical type of relationship in which one feeds from the other and from itself, growing and getting increasingly complex with each cycle. It represents the cybernetic paradigm where mysticism and rationality work together and act as motor for human curiosity.

Chapter 6

Conclusion

This thesis has presented four projects that were developed in order to explore how art and science interact to construct our reality. The concepts of perceived reality against fixed reality were examined through the lens of biofeedback systems that allow immediate retrieval and interaction with both realities. The development and implementation of a performative system where those concepts are in interaction is embedded in the Cyborg performance.
Furthermore, other concepts about how we interact with reality through science and technology were explored through the implementation of virtual and augmented reality systems.

6.1 Artistic Outcome

As discussed in Chapter 1, music has fascinated the human mind since the Ancient Greece, both in scientific study and also in the practice of esoteric mystical traditions, because it is at the same time an acoustic science and an emotional experience. It is amazing to think that many of our current music technologies originally had nothing to do with music. A lot of the musicians' favorite hardware (synthesizers, compressors) comes from the scientific community, and the biofeedback process is increasingly implemented by artists. But even before new technologies appeared, the union of art and science can be revealed in music more than in any other art. Indeed, music is decomposed in ratios between notes, and music theory is structured in a very rational mathematical way. However, music and its acoustic behaviors influence our mind and how we perceive reality. All matter in the universe has a particular frequency at which it starts to resonate, meaning that particular sound frequencies can stimulate human bodies and minds either in a good or in a bad way. Even if tempered tuning systems nowadays are using 440 Hertz as reference tone, it is known that pre-tempered music was tuned to other frequencies than 440, because people felt more connected with the resulting sounds coming from that tuning, caused

by a longing cultural exposure to it. Although the neural mechanisms that dictate what is consonant and what is not are still debated, there is an agreement that some of the intervals are more consonant than others who seem more dissonant. The reason why we find pleasure in a consonant sound such as a perfect fifth interval might be because its ratio (3/4 in equal temperament) is a rational number that our brain can naturally associate with, whereas dissonant intervals like a triton has a ratio of the square root of 2, an irrational imaginary number that our brains have a hard time associating with, hence that interval was banished from music for centuries because it was thought to be the devil's interval (diabolus in musica)[35].

For me, music represents the perfect intersection of art and science and where human creativity has the most space for development. Indeed, modern music approaches do not set boundaries about what other elements to incorporate into their expressions. Whereas other modern artistic approaches use music as a support for their statement, music has breached all boundaries to the point where today we can find live painting as part of musical performances, live animations used as music scores, visually beautiful and elegant graphical scores, as well as operas, musical theater, dancing music. The main artistic outcome of this project is the MVM biofeedback music system. Having an unusual first interaction with reality and growing up in constant interaction with biofeedback systems has determined and set up the base for the artistic output that was stated in this thesis.

6.2 Social Outcome

Open source software and hardware was used in the realization and implementation of all of the projects presented in this thesis. For the muse headband, it is true that the hardware is not free but the software is open source that allows to write personalized code to it. Nevertheless, that is one of the reasons why a low cost, custom-made brain detector interface was necessary, in order to try another approach that could be affordable and ready to use for anyone. This means immediate medical approaches to use these devices such as helping patients with brain or heart diseases to be able to generate audio-visual reactions to their vital signs. Furthermore, the accessibility and implementation of cheap open source software and hardware makes this system an available and accessible teaching tool for music technology.

6.3 Final Thoughts

After two years working on these projects I feel that a lot has been accomplished in terms of biofeedback music and the exploration of reality through art and science. Devices such as the HeartDetektor and the EEG circuit were created in order to provide cheap and quick accessibility to integrate them with any musical performance. It allows musicians to be more aware of their bodies when they are performing and to correlate their biofeedback output with their current performance. I feel that there is a lot of unexplored potential that can be revealed by bringing biofeedback interaction not only into music but also into arts in general.

Another topic of this thesis was to see whether modern interactions with reality such as augmented and virtual reality could be seen as biofeedback techniques. I think they are definitively biofeedback processes in which sensorial information is retrieved from within the environment or from the users, and is processed and transformed into new stimuli that are then re assimilated by the same users. They represent an advantage to improve our senses but also we must not rely only on technological gadgets because we take the risk of becoming completely dependent on them.

I would also like to write a small personal reflection about what this process of writing a thesis and doing a Master's degree represents to me. These past two years have helped me develop a more critical and at the same time empirical approach with my own reality. I have found inspiration in my own human condition that has guided my interaction with reality, and from that inspiration comes all this personal reflection about what is real and what is not, and how the tools that we created (art and science) help us carry on with our daily routines. In a personal way, I feel that this experience of pursuing a higher education title has helped me find my real identity, which now I cannot define as barely being a musician or sound engineer. I feel that this whole process is about slowly mastering several areas of knowledge and accept that like Newton said "we are stepping on shoulders of giants", meaning that we success only if we work as a whole, collaborating and sharing ideas and knowledge with the world. On another side, more philosophical questions about the role of technology and science in both the Arts and our daily life have become more constant within me. We are embracing technology in an extremely fast rate, children that are born these days will probably never interact with old technologies like

compact discs or floppy disks, but it's amazing to see how intuitive for them new technologies are, they have developed an evolutionary adaptation to this new cybernetic world. It is extremely important that we preserve what make us human beings and both art and science provide a field for pursuing that. It is important that we never stop teaching our children how to handwrite or how to draw and paint with physical color, how to play physical instruments and so on. It used to be a time when people would say "my phone is running out of batteries", but these days' people talk about their technological devices as if they were part of them. "I'm running out of batteries" is what one would hear nowadays. This reveals a symbiotic reaction to technology, which people need to be aware of.

This leads to finally reveal the connections between Art and science. The work of both artists and scientists involves similar stage of development (brainstorming or hypothesizing ideas), followed by testing and refining stages, that often lead to additional creative problem-solving. Both have been collaborating since mankind developed those concepts, they provide support to try to answer the most fundamental questions of the universe and are driven not by a utilitarian capitalistic purpose of self-benefit, but by the motor that had led us until all what we know today, human curiosity. Artist's studios and scientists' laboratories are the playground in which both fields experiment and create, with an open-ended state of interpretation and reinterpretation of their work.

6.4 Future Work

The results of this research have provided valuable approaches and implementations of scientific concepts applicable to the arts. First, with the development of open source and hardware biofeedback devices, it will be possible to reproduce those in meaningful quantities to both help people with medical issues to release their creativity but also to be implemented as a more professional tool of composition for large ensembles such as big bands or orchestras in which all musicians will be wearing biofeedback devices. Other ideas are that could implement technologies and concepts exposed in this thesis have also been envisioned such as a Virtual Reality head set with electrodes to read EEG data from the forehead.

This research could also benefit from a more scientific approach to the data that is being retrieved from the musicians on stage. Indeed, if the biofeedback data from musicians in an orchestra it is retrieved and analyzed, it might be possible to detect some kind of synchronism between different sections of the orchestra or in the orchestra as a whole, embracing the neural network metaphor in which multiple little musician's brains (neurons) constitute a larger more complex system which is the orchestra (brain).

"Follow your heart, but bring your brain with you."

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